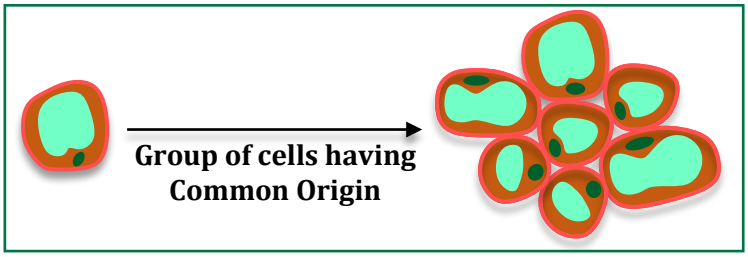
02 Anatomy of Flowering Plants

1. Introduction :

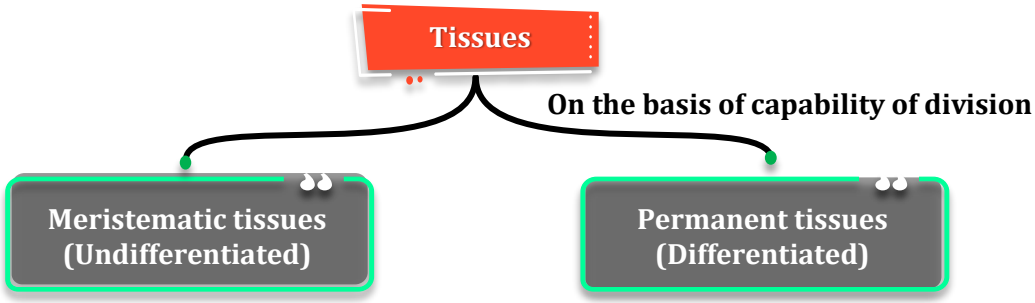
- Plant and animals both show the structural similarities and variations in their external morphology as well as in their internal structure (Anatomy).
- Different organs in plants show variations in their internal structures.
- The monocots and dicots are also seen to be anatomically different.
- Internal structural also show adaptations to diverse environments.
- The branch of botany which deals with study of internal structures and organization of plants or plant organs (plant parts) is known as **plant anatomy** / Study of internal structure of plants is called plant anatomy.

N. Grew (Nehemiah Grew) is known as father of plant anatomy.
Note : Book - "The anatomy of seed plants" was written by **Katherine Esau (K. Esau)**. It was published in 1960. It was referred to as Webster's of plant biology. It is encyclopediac.

Tissue :
A group of cells having a common origin and usually perform a common function is called tissue.
The term tissue was coined by **Nehemiah Grew**.



The tissues were divided into two groups by **Karl Nageli** :-



- **Cell have capacity of division**
- **Composed of immature cells**

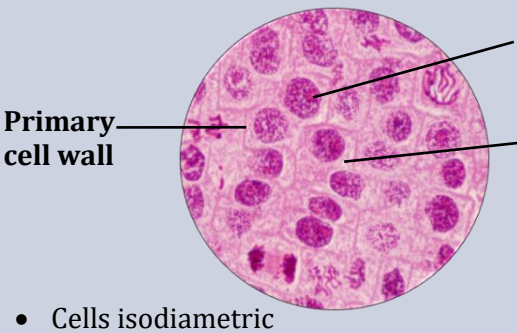
- **Cells have lost the capacity to divide**
- **Either temporally or permanently**
- **Composed of mature cells**

2. Meristematic Tissue :

- **Meristem :** Growth in plants is largely restricted to specialised regions of active cell division called meristems/ A meristem is a localised region in which actual cell division occurs.
- Meristem term was given by **Nageli**. It is derived from a Greek word **meristos** (means **Divided/ Divisible).**

(1) Characteristics of Meristematic tissue

- It is an **undifferentiated tissue**.
- Cells of meristem are in continuous state of division. Thus, meristematic tissue is composed of **immature cells.**
- Meristematic cells have only primary cell wall which is thin and flexible (elastic) and made up of cellulose with abundant plasmodesmatal connections.
- Secondary cell wall is absent.
- Cells of meristem are small and generally isodiametric.
- They have dense cytoplasm.
- They have prominent and large nucleus.
- Normally vacuoles are absent in meristematic cells, if present then they are small in size.
- Meristematic cells are metabolically highly active, so reserve food is absent in these cells.
- Plastids are absent in meristems. If they are present, then only in the proplastid stage.



- Cells isodiametric
- Metabolically highly active, reserve food absent
- Plastids, vacuole, ergastic substances and intercellular spaces absent

- They do not have intercellular spaces. Cells are closely arranged/closely fitted (packed) together, so it is a **compact tissue.**
- Ergastic (non-living) substances are almost absent. e.g. Resin, Mucilage, Rubber.

(2) Classification of Meristematic Tissue/Meristem :

(i) Meristem based on Origin and Development :

On the basis of origin and development meristems can be divided into following three types :-

(a) Promeristem/Primordial Meristem/Urmeristem :

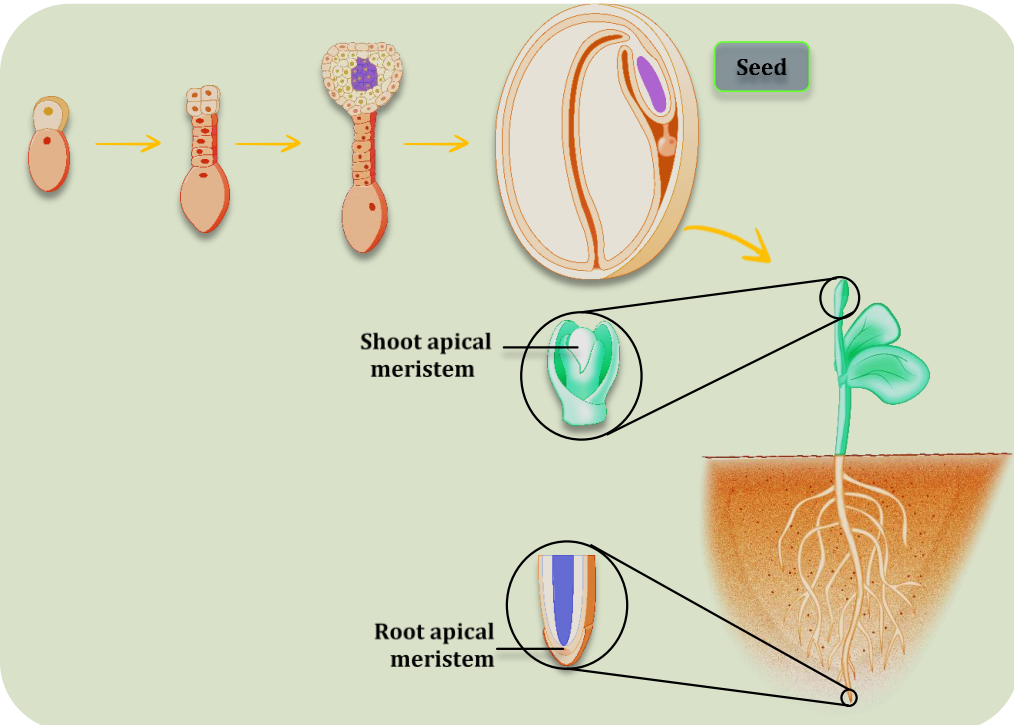
- This meristem develops in the beginning during embryonic stage. It forms primary meristem.
  e.g. Embryonic meristem

(b) Primary Meristem :

- Meristematic cells developed from promeristem are known as primary meristem.
- It appears early in the life of a plant & contribute to the formation of the primary plant body.
- Cells are always in division phase and form primary permanent tissue by the process of differentiation.
  e.g. Apical meristem, intercalary meristem, intrafascicular cambium or Fascicular vascular cambium.

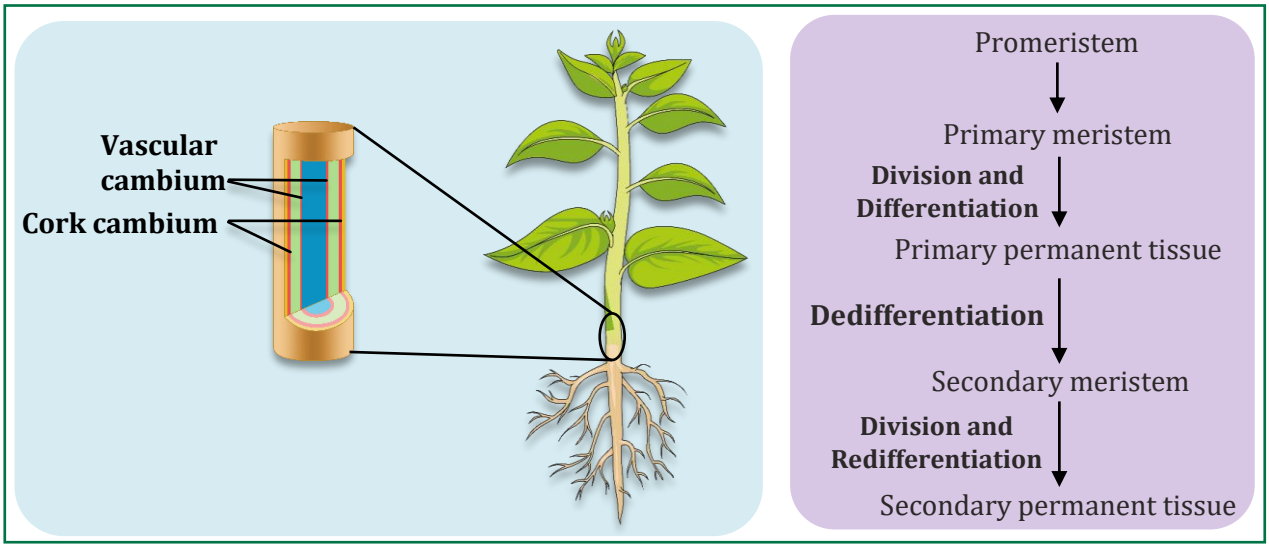
TG: @Chalnaayaaar

TG: @Chalnaayaaar



(c) Secondary meristem :

- Secondary meristem develops from primary permanent tissue by the process of **dedifferentiation**.
- Secondary meristem appears later than primary meristem.
- By the activity of secondary meristems, secondary growth takes place ***e.g.*** Interfascicular cambium & cork cambium of dicot stem, vascular cambium & cork cambium of dicot root.



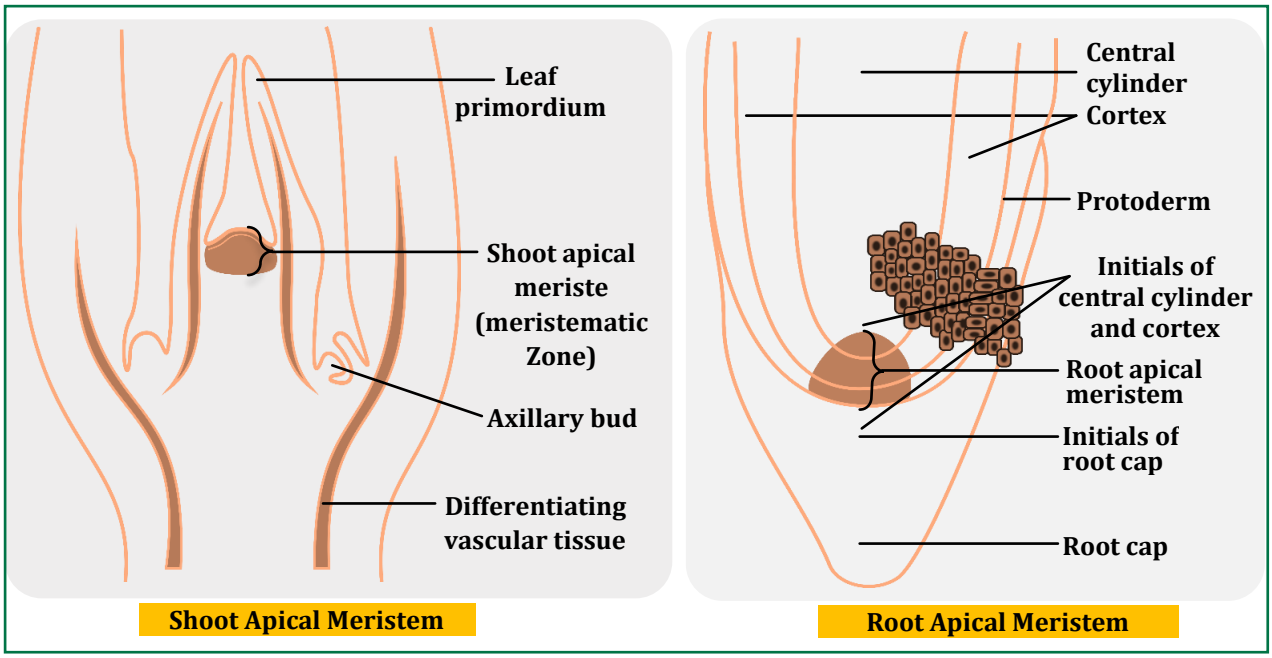
(ii) Meristem based on location (position) in plant body :

On the basis of position, meristems are divided into three types :-

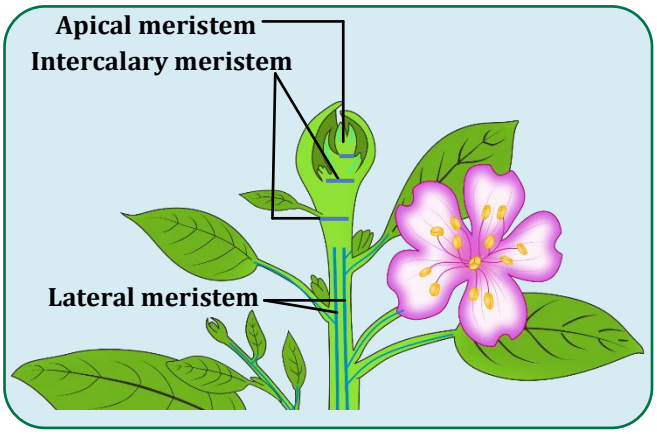
(a) Apical Meristem :

It is an example of primary meristem. The meristems which occur at the tips of roots and shoots and produce primary tissues are called apical meristems. They are responsible for increase in the length of plant organs. It means they are responsible for primary growth. Examples of apical meristem: - **Root apex/root apical meristem, shoot apex/shoot apical meristem**.

TG: @Chalnaayaaar



(b) Intercalary Meristem:



- It is an example of primary meristem.
- It is present at the base of internode of monocots stems ***e.g.*** grasses, bamboo, sugarcane etc. It is also present at the base of leaves. By the activity of this meristem, length of leaves increases.
- Intercalary meristem occurs between mature tissues.
- By the activity of this meristem length of the plant organs increases.
- They occur in grasses and regenerate parts removed by the grazing herbivores.
- **Both apical meristems & intercalary meristems are primary meristems because they appear early in the life of a plant and contribute to the formation of primary plant body.**

(c) Lateral Meristem :

- Lateral meristem occurs on lateral side of plant organs.
- Activity of lateral meristem increases the **circumference/girth/thickness of plant organ**.
- All secondary meristems are lateral meristems.
- Lateral meristems are both primary and secondary in origin (mostly secondary in origin).

Primary lateral meristems :- Intrafascicular cambium /fascicular cambium.
Intrafascicular cambium /fascicular cambium:- This cambium occurs inside the vascular bundles of dicot stems and gymnosperms stems.

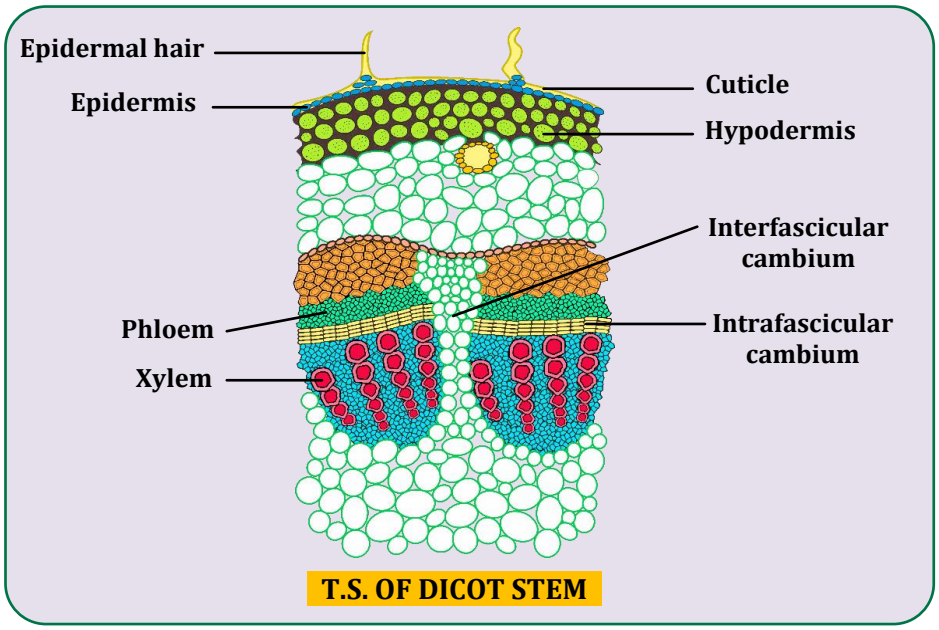
Secondary lateral meristems :- Interfascicular cambium and cork cambium (phellogen) of dicot stem and gymnosperm stem, Cork cambium and vascular cambium of dicot roots are examples of secondary lateral meristems.

TG: @Chalnaayaaar

Note : Generally lateral meristems are cylindrical.

The meristem that occurs in the mature regions of roots and shoots of many plants, particularly those that produce woody axis and appears later than primary meristem is called the secondary meristem.

- During the formation of leaves and elongation of stem, some cells "Left behind" from shoot apical meristem, constitute the axillary bud. Such buds are present in the axils of leaves and are capable of forming a branch or a flower.
- Root apical meristem occupies the tip of a root while shoot apical meristem occupies the distant most region of the stem axis



Theories Regarding Organisation of Apical Meristem :

(1) Histogen Theory :

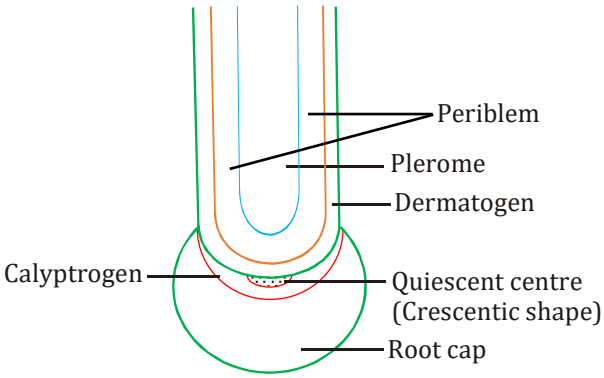
- This is most valid theory for root apex organisation.
- This theory was proposed by Hanstein (1870).
- According to Hanstein, the apical meristem (root and shoot apices) are distinguished into three histogens (meristematic regions). These are as follows.

(i) Dermatogen :- This is the outermost histogen & composed of single layer of cells. These cells form uniseriate (single layered) epidermis.

(ii) Periblem :- This region is situated just below the dermatogen. It forms cortex (hypodermis, general cortex and endodermis).

(iii) Plerome :- This is the innermost histogen. Stele formation takes place by division of these cells. It means formation of pericycle, vascular bundles, pith rays /medullary rays and pith/medulla.

- **This theory is true only for root apex. It is not applicable for shoot apex of higher plants** because in most of the gymnosperms and angiosperms, shoot apex is not differentiated into three histogens.



Schematic representation of monocot root apex showing different types of histogen.

- Including above described three histogens, a fourth histogen is also present in **monocotyledon root apex**. This is known as **calyptrogen. Root cap is produced by calyptrogen in monocots. Root cap & epiblema/epidermis are produced by dermatogen in dicotyledons.**

Quiescent centre :-

- Quiescent centre term was coined by "Clowes". Quiescent centre was discovered by Clowes in Maize root.
- A group of inactive or less active cells present between the dermatogen and calyptrogen of monocot root is called quiescent centre. The cells of quiescent centre contain less amount of DNA, RNA, light cytoplasm, small nuclei and synthesis of protein is also less.
- Quiescent centre is crescentic shaped.
  Function : The quiescent centre in the root meristem serves as a reserve for replenishment of damaged cells of the meristem or Inactive cells of quiescent centre become active when previously active initials of calyptrogen get damaged.

(2) Tunica Corpus Theory :

- This theory was proposed by Schmidt (1924). It is most valid theory for shoot apex organisation of angiosperms. It is based on planes of division. According to this theory two zones are found in the shoot apex:-

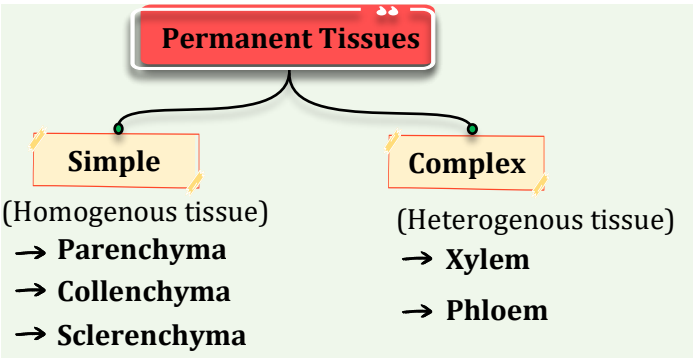
(I) **Tunica :** This is peripheral layer. Epidermis is formed by tunica.

(II) **Corpus :** The mass of cells present below the tunica is called corpus. The cells of this zone divides in all directions (all planes) due to which volume increases. The cells of corpus usually larger than the cells of tunica.

TG: @Chalnaayaaar

3. Permanent Tissues :

- Permanent tissues are composed of cells which have lost the power of division temporarily or permanently.
- They are formed by division and differentiation of meristematic tissues.
- The cells of permanent tissues do not generally divide further. Their cells may be living or dead.



Simple Permanent Tissue :

This tissue is made up of structurally similar type of cells or only one type of cells that perform a common function. Simple tissues are of three types :-

(1) Parenchyma
(2) Collenchyma
(3) Sclerenchyma

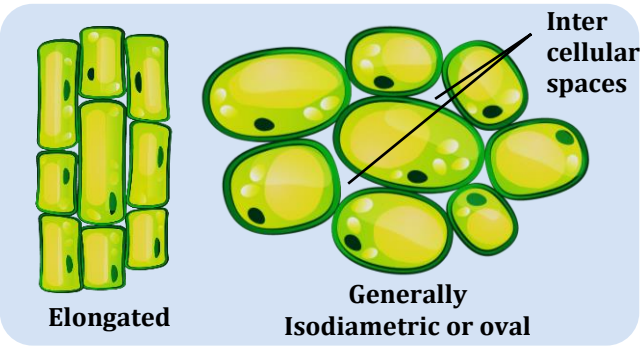
(1) Parenchyma :

It is very primitive type of tissue. It is first evolved tissue. Remaining different types of tissues are derived from this tissue, so it is also called fundamental tissue or precursor of other tissues. Parenchyma forms the major component within organs.

Parenchyma term was coined by Grew.

Characteristic Features :

- It is a living tissue.
- It is first differentiated tissue.
- It is a **universal tissue**.
- Pulp of a fruit is mainly composed of parenchyma.
- Body of bryophytes is mainly composed of parenchyma.
- The cells of parenchyma are **thin walled**. Cell wall is made up of pectocellulose means pectin + cellulose **(mainly cellulose)**. So, parenchyma is a soft tissue.
- Each cell contains large central vacuole. So, the main function of a parenchyma cell is storage of food.
- **Parenchymatous cells may either be closely packed or have small intercellular spaces.**
- It is found in cortex, pericycle, medullary rays, pith, leaf mesophyll etc. **It forms major component within organs.**



Shape :

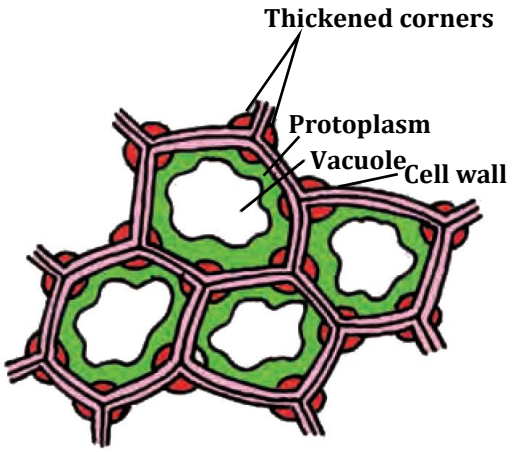
- **The cells of parenchyma are generally isodiametric. They may be spherical (rounded), oval, elongated or polygonal in shape.**

TG: @Chalnaayaaar

Functions of parenchyma :

- The parenchyma performs various functions like storage, photosynthesis, secretion etc.
- The main function of this tissue is storage of food.
- Some cells of parenchyma store waste materials.
- When cells of parenchyma develop chloroplast, known as chlorenchyma and it performs photosynthesis.

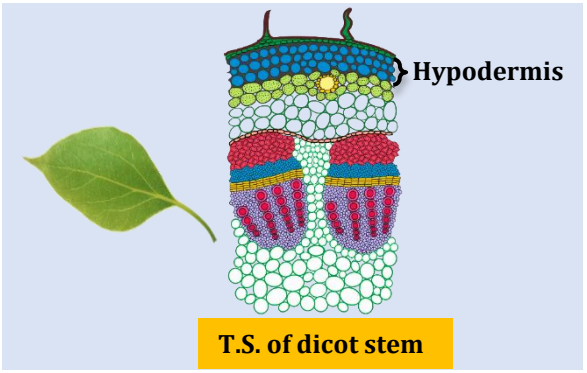
(2) Collenchyma : Term was coined by Schleiden.



Main characteristics :

- Collenchyma is a **living mechanical tissue.**
- It is made up of more or less elongated cells (In transverse section cells appear oval, spherical/ rounded or polygonal in shape).
- Localized **deposition of pectin (mainly), cellulose & hemicellulose** occurs mainly **at corners.**
- **Usually intercellular spaces are absent.**
- Generally, chloroplasts are found in the cells of collenchyma or **cells often contain chloroplasts.**
- **These cells assimilate food when they contain chloroplasts.**

Occurrence :



- Collenchyma is not a universal tissue. It is found in the stems of herbaceous dicotyledons (young dicot stem) below the epidermis either as a homogenous layer (in sunflower stem) or in patches (in Cucurbita stem).
- Collenchyma forms the hypodermis of dicotyledon stems. Cells of collenchyma are flexible due to hydrophilic nature of pectocellulose, so flexibility occurs in dicotyledonous/dicot stems.
- Margins of leaf lamina and petiole of leaves also bear collenchyma. It protects the lamina margins from cracking by the action of wind.
- Collenchyma is absent in mature/woody plant parts (After secondary growth in dicot stem), roots and monocotyledons.

Functions :

- Collenchyma performs both functions mechanical as well as biological/vital functions. Provides tensile strength against bending & swaying (mechanical function).
- They provide mechanical support to the growing parts of the plant such as young stem and petiole of a leaf.
- Due to the presence of chloroplast, photosynthesis process (assimilation of food) takes place in collenchyma (vital function).

TG: @Chalnaayaaar

(3) Sclerenchyma : Term was coined by **Mettenius**.

Main features :-

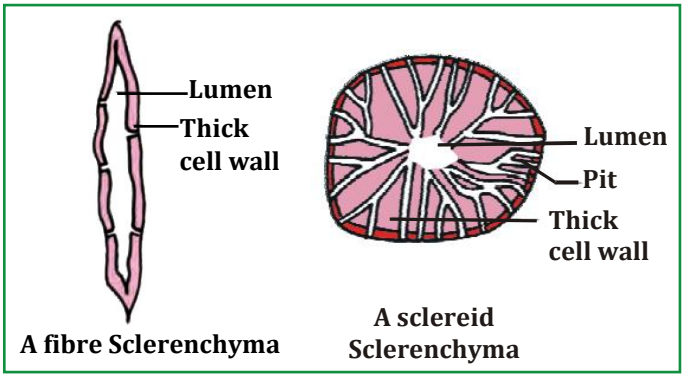
- Sclerenchyma is the **main mechanical tissue**. It is **dead mechanical tissue**.
- **Cells of sclerenchyma are generally long, narrow, thick walled, lignified without protoplasts and dead** (Cells become dead at maturity).
- Sclerenchyma is found in the **hypodermis of monocot stem**.
- **Function : It provides mechanical support/mechanical strength to plant organs**.
- Various types of pits are formed due to the **deposition of lignin on the walls**.

Types of sclerenchyma :-

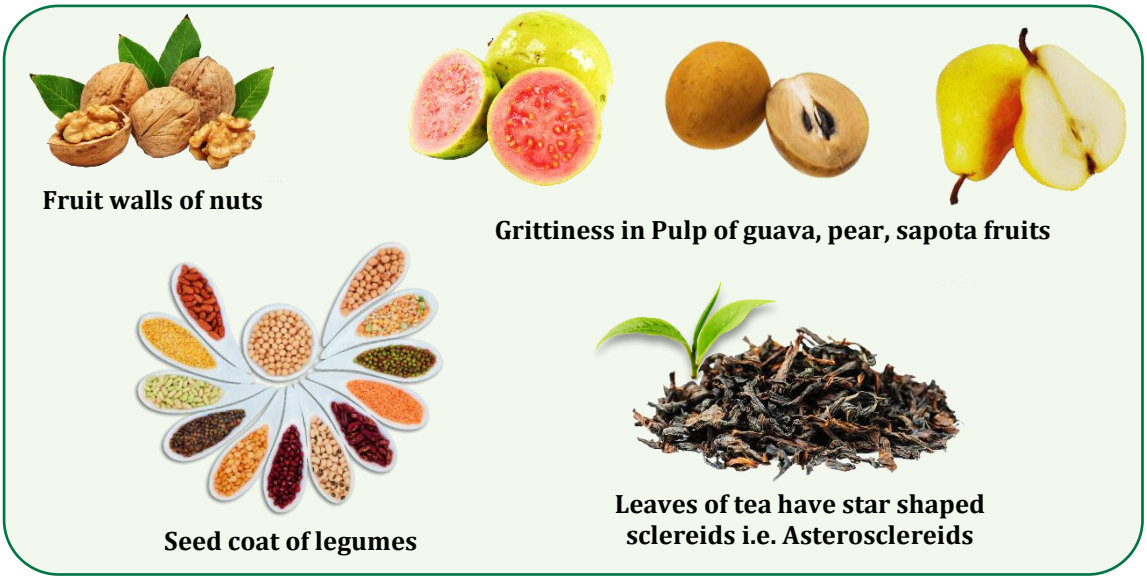
On the basis of variation in form, structure, origin & development, sclerenchyma cells are of two types.

(I) Sclereids

(II) Sclerenchymatous fibres



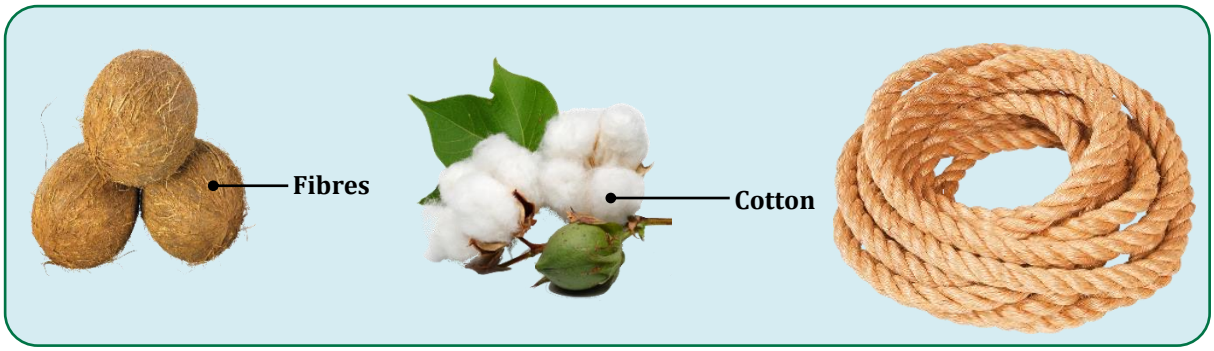
I. Sclereids : These cells are small, dead extremely thick walled **(highly thickened)** and generally their ends are not pointed. Sclereids are of various shapes (Spherical, oval or cylindrical). Sclereid cells have pits and **lumen (cavity) is almost very small/very narrow. Sclereids are commonly found in fruit walls of nuts, pulp of guava, pear & sapota (Stone cells); seed coats of legumes and leaves of tea etc.**


Fruit walls of nuts
Grittiness in Pulp of guava, pear, sapota fruits
Seed coat of legumes
Leaves of tea have star shaped sclereids i.e. Asterosclereids

II Sclerenchymatous fibres :- The fibres are thick walled, elongated and pointed cells.

- **Fibres are longest cells in plant body. Their both ends are pointed** (tapering). Due to **thick cell wall, lumen is reduced** and generally occurring in groups in various parts of the plant.

TG: @Chalnaayaaar



- On the basis of position, fibres are divided into three types -

A. **Surface fibres :** They are present on the surface of seeds, fruits etc. These fibres are also called filling fibres.

(i) **Seed surface fibres -**

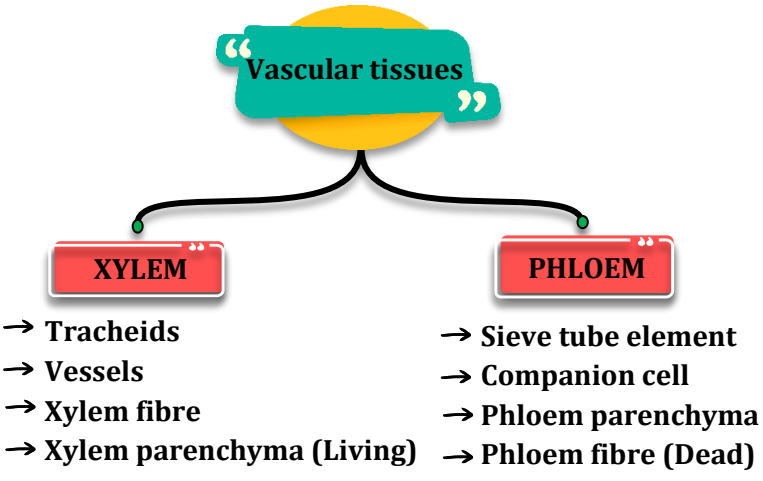
- **Cotton fibres** (Gossypium fibres) - Cotton fibres are **out growth of seed coat/Testa**. Cotton fibres are composed of **cellulose**. They are **non-lignified**. So cotton fibres are not true fibres. Two types of fibres are found in cotton. Long fibres are called **'lint'** and small fibres are known as **'fuzz'**. Lint fibres are used in cloth industry. Fuzz are filling fibres.

(ii) **Coir of coconut** is also a type of surface fibres. They are derived/obtained from the fibrous mesocarp of coconut (Cocos nucifera). These are **true fibres**, because they are **lignified**.

B. **Xylary fibres/Intraxylary fibres/Wood fibres :** These are hard fibres. These fibres are not flexible. These fibres are obtained from xylem (mainly from secondary xylem or wood).
Ex. Munj fibre (Saccharum munja)

4. Complex Permanent Tissue :

- The complex tissues are made of **more than one type of cells** or **different types of cells** and these works together as a unit. Complex tissues are **heterogenous**.
- Complex tissues are **absent** in **gametophytes**.
- **During vascularisation in plants differentiation of procambium is followed by the formation of primary phloem and primary xylem simultaneously**.
- Complex tissues are also known as **vascular tissues** or **conducting tissues**.



TG: @Chalnaayaaar

(1) Xylem :

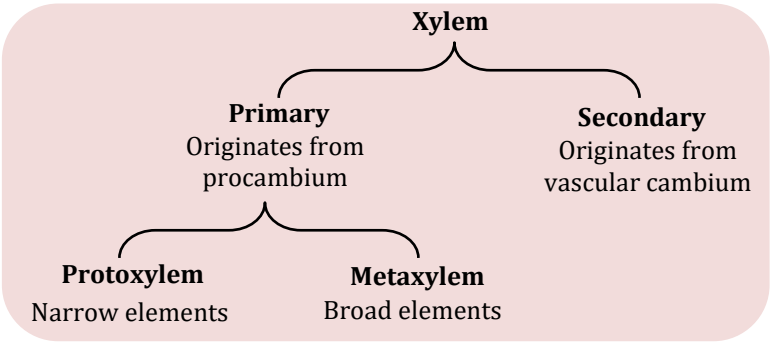
- The term 'Xylem' was coined by **Nageli**.
- The function of xylem is to **conduct water & mineral salts** upwards from the roots to stem & leaves and to give **mechanical strength** to the plant parts.
- For efficient conduction of water death of protoplasm is must. Dead tissues are more developed in water scares conditions.
- **In hydrophytes xylem is poorly developed, while in xerophytes xylem is well developed.**
- On the basis of **origin**, xylem is divided into primary xylem and secondary xylem.

(i) **Primary xylem :** originates from procambium during vascularisation. Xylem which is formed early in the life of a plant is known as primary xylem. On the basis of development primary xylem is divided into two types.

(a) Protoxylem

(b) Metaxylem

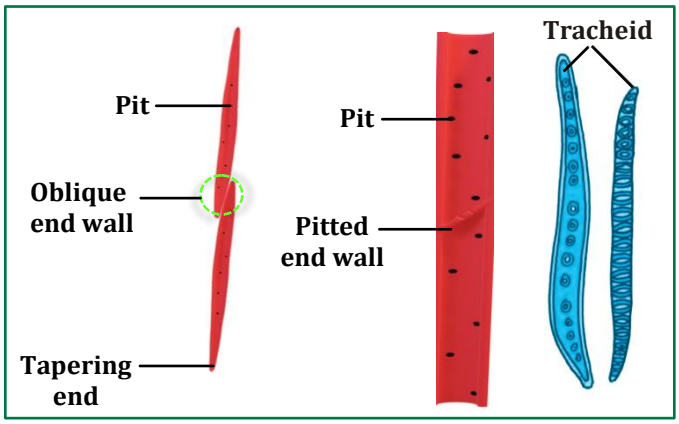
- Cells of protoxylem are small as compared to metaxylem. The first differentiated primary xylem elements are called protoxylem and the later formed primary xylem is called metaxylem.



(ii) **Secondary xylem** :- originates from vascular cambium during secondary growth. Xylem which is formed during secondary growth is known as secondary xylem. **Secondary xylem is not differentiated into protoxylem and metaxylem**.

1. Tracheids :

- Tracheids are primitive conducting elements of xylem.
- A single tracheid is elongated or tube-like cell with thick and lignified walls and possess a narrow lumen. The ends of tracheids are tapering or chisel like.
- The tracheids found one above the other and are separated by cross wall / end wall which bears bordered pits.
- Usually **bordered pits** are present at the end walls of tracheids.



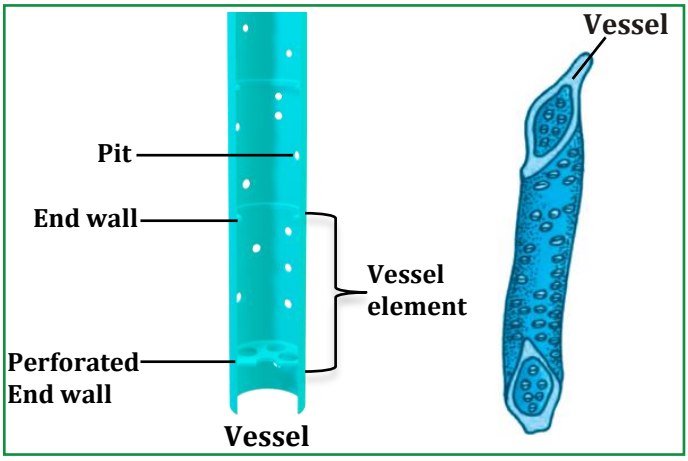
TG: @Chalnaayaaar

The maximum bordered pits are found in the tracheids of Gymnosperm plants.

- Tracheids are dead (without protoplasm) and lignified cells.
- Tracheids are found in all vascular plants i.e. pteridophytes, gymnosperms and angiosperms.
- End walls of tracheids are **imperforated** (not porous) but **pitted** (Pits are present).
- Tracheids are unicellular.
- The inner layers of cell walls have thickenings which vary in form.
- Types of thicknening in tracheids and vessels are annular, spiral, reticulate, pitted and scalariform.
- The deposition of lignin on cell wall is responsible for the formation of different types of thickenings i.e., annular **(primitive type)**, spiral, scalariform, reticulate and pitted.
- **Annular** and **spiral** type of thickenings of lignin are found in **protoxylem**.
- **Reticulate** and **pitted** (mainly) type of thickenings of lignin are found in **metaxylem.**
- **Scalariform** (ladder like) type of thickening is found in metaxylem tracheids of **pteridophytes** and in metaxylem tracheids of ***Cycas (gymnosperm).***
- Maximum deposition of lignin is found in pitted type of thickening and pits are formed in this type of thickening. **Pits** are unlignified areas on lignified walls.

2. Vessels = Tracheae :

- Vessel is an **advanced conducting element of xylem.**
- Vessel is a long cylindrical, tube like structure with lignified walls and **a wide (large) central lumen/cavity.**
- Vessel is multicellular, it is made up of many cells called vessel members or vessel elements.
- Vessel is an example of **dead syncyte**. Vessel cells are also devoid of protoplasm.
- The **end wall is perforated**. Thus, vessels are more capable for conduction of water than tracheids. Due to presence of perforated end walls, vessels **work as a pipe line** during conduction of water.



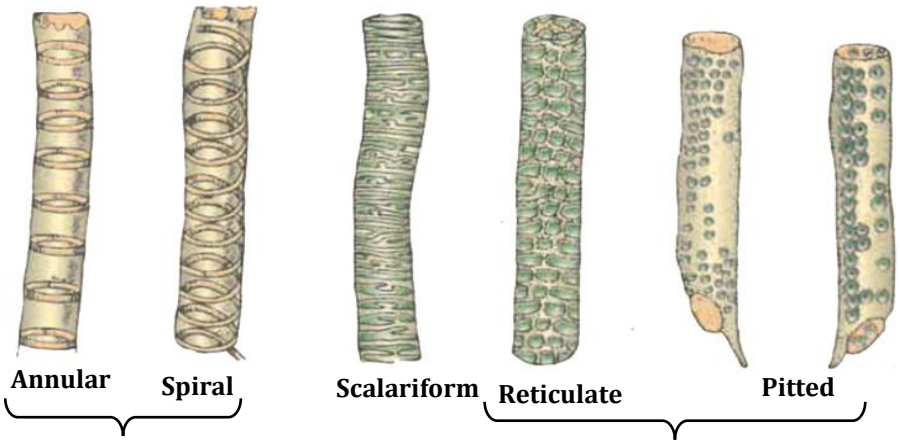
- Vessel members are interconnected through perforations in their common walls. The perforation may be **simple** (only one pore) or **multiple** (several pores). Vessels contain **usually simple pits** on their lateral walls.

1. **Presence of vessels is a characteristic feature of angiosperms Vessels are usually absent in gymnosperms** but exceptionally vessels are present in **some gymnosperms like *Ephedra, Gnetum* and *Welwitschia*** (order Gnetales).
2. Vessels are **absent in some** angiosperm **plants** such as ***Dracaena, Yucca, Dagenaria, Drimys.*** There are some angiosperm families in which vessel less angiosperms are included.
   e.g. **Winteraceae, Tetracentraceae** and **Trochodendraceae.**
3. Tracheids and vessels are called tracheary elements of xylem.
4. In flowering plants, tracheids and vessels are the main water transporting elements.

Syncyte : Structure which is formed by fusion of cells is called syncyte.

TG: @Chalnaayaaar

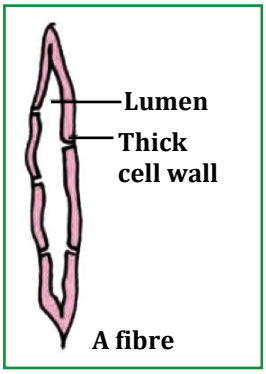
TG: @Chalnaayaaar



Different types of thickening on the walls of tracheids and vessels

3. Xylem Fibres = Wood Fibres :

- They may either be septate or aseptate.
- Xylem fibres provide strength to the tracheids and vessels.
- They have highly thickened walls and obliterated central lumens.
- They are **abundantly** found in **secondary xylem (wood)**.
- They are generally not found in gymnosperm wood (so, **gymnosperms are also called soft wood spermatophytes**).



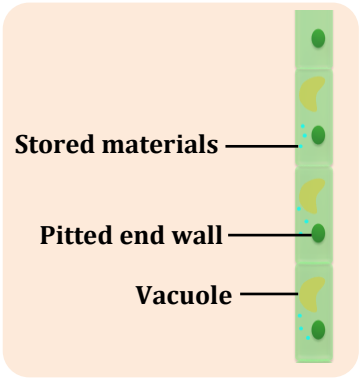
4. Xylem Parenchyma :

- Cells living and thin walled and their cell walls are made up of cellulose.

Function :-

Storage of food materials in the form of starch or fat and storage of other substances like tannins.

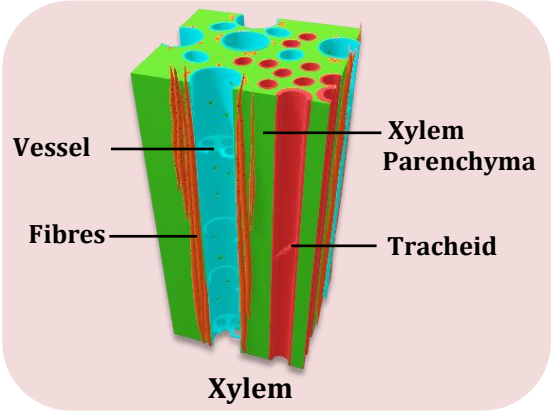
Note :- Function of ray parenchymatous cells (xylem rays) radial conduction of water.



Hadrome :-

Conducting part of xylem is known as hadrome.

Tracheids and vessels are collectively known as water conducting elements or "**Hadrome**". Hadrome term was proposed by Haberlandt.



TG: @Chalnaayaaar

(2) Phloem :

- The term 'Phloem' was coined by **Nageli**.
- The main function of the phloem is **to conduct/transport food material,** usually from the leaves to other parts of the plant. On the basis of origin, phloem is classified into two categories primary and secondary phloem.
- **Primary phloem** originates from procambium during vascularisation and **secondary phloem** originates from vascular cambium during secondary growth. On the basis of development primary phloem is categorised into protophloem and metaphloem.
- The **protophloem** (first formed primary phloem) has narrow sieve tubes whereas metaphloem (later formed primary phloem) has bigger sieve tubes.
- Phloem remains active for less duration as compared to xylem.
- Phloem consists of **4 types** of cells / elements :-
- **Sieve tube elements, companion cells, phloem parenchyma & phloem fibres (In angiosperms).**
- **Sieve cells, albuminous cells, phloem parenchyma & phloem fibres (In gymnosperms).**

(i) Sieve Cell / Sieve Tube Element :

↓ ↓

In Gymnosperms and pteridophytes | **In Angiosperms**

1. Sieve element was discovered by **Hartig**.
2. **In Angiosperm plants**, sieve tube elements are joined with their ends to form **sieve tube**. Their end walls are perforated (means having sieve pores) in a sieve-like manner to form the sieve plates (oblique perforated septa). Translocation of food material takes place through these pores. Sieve tube is an example of **living syncyte**.
3. Sieve tube elements are long, tube like structures arranged longitudinally and are associated with companion cells.
4. Sieve cells and sieve tube elements are living and thin walled.
5. A mature sieve tube element possesses a peripheral cytoplasm & a large vacuole but lacks a nucleus.
6. Mature sieve tube elements are enucleated living cells (enucleated means without nucleus).
7. The function of sieve tubes is controlled by the nucleus of companion cells.
8. A central large vacuole is present in each sieve cell and sieve tube element and around the central vacuole thin layer of cytoplasm is present.

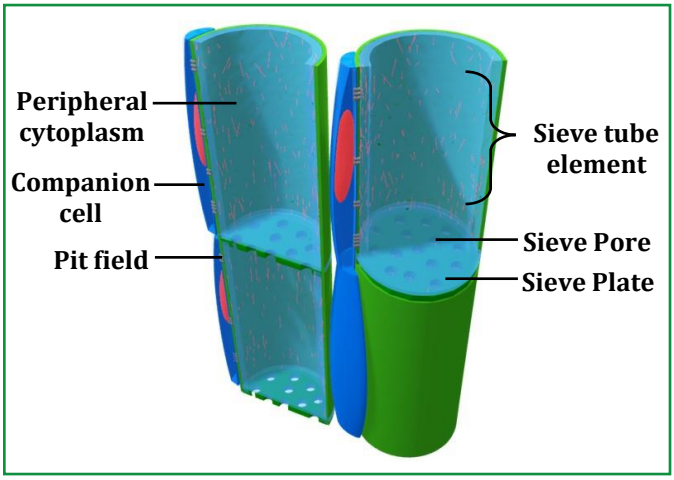
Note :-

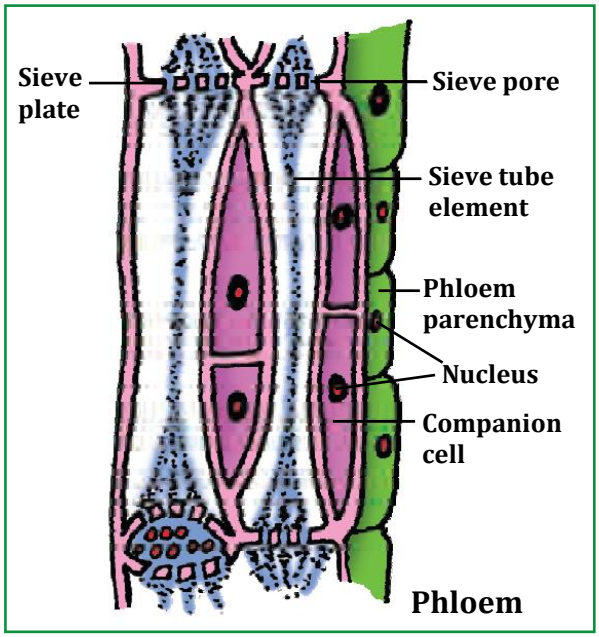
- **Callose** deposition takes place on the radius of sieve pores during dropping season/falling season of leaves (autumn), to form a thick layer. This is called callus pad /callose pad. It is formed mainly in deciduous plants.
- Sieve plate is protected by callose pad. It protects sieve plate from bacterial infection and drought (dry ness).
- Callose dissolves during spring season. Callose is a polymer of **β-1, 3-glucan.**
- Sieve elements contain special type of protein-**P-protein** (p=phloem). Most likely function of p-protein is sealing mechanism on wounding along with callose and it is also related with conduction of food.

TG: @Chalnaayaaar

TG: @Chalnaayaaar

- In Pteridophyte and gymnosperms, sieve cells are arranged in zig-zag manner. In sieve cells, sieve areas are located laterally. Sieve cells are narrow elongated cells.





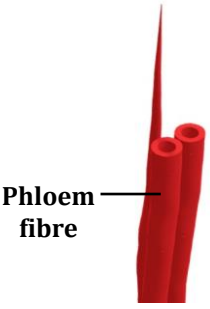
(ii) Companion Cells :

- These are thin walled, living, **specialised parenchymatous cells**, which are closely associated with sieve tube elements.
- The sieve tube elements and companion cells are connected by **pit fields** present in their common longitudinal walls.
- Companion cell is laterally associated with each sieve tube element in angiospermic plants.
- **Sieve tube element and companion cell** originate together. Both of them originate from a single mother cell. So, they are called **sister cells**.
- Companion cell is a **living cell** with **large elongated nucleus**. This nucleus also controls the activity/functions of sieve tube element.
- Companion cells are found only in **angiosperms**.
- The companion cells help in maintaining the pressure gradient in the sieve tubes.

Note:- Special type of cells are attached with the sieve cells in **gymnosperm and in pteridophytes** in place of companion cells. These cells are called **albuminous cells/Strasburger cells**.

(iii) Phloem Fibres / Bast Fibres :

- These are made up of **sclerenchymatous** cells.
- These are much elongated, unbranched and have pointed needle like apices. The cell wall of phloem fibres is quite thick.
- These fibres are generally not found in primary phloem but are found in the secondary phloem.
- These fibres **provide mechanical support** to sieve elements.
- At maturity fibres lose their protoplasm and become **dead.**

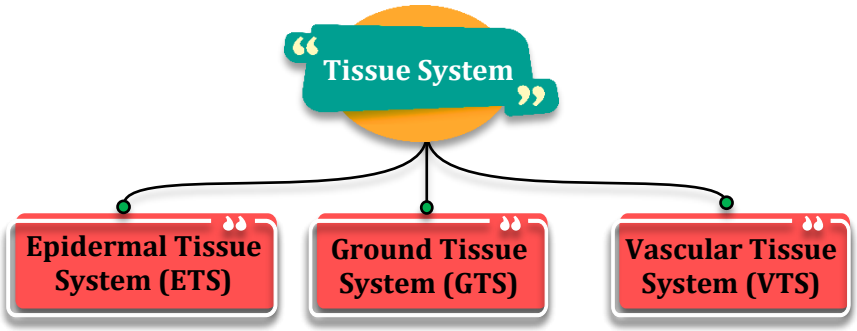


TG: @Chalnaayaaar

(iv) Phloem Parenchyma :

- It's cells are **living, elongated, tapering**, cylindrical which have dense cytoplam and nucleus.
- **The wall is composed of cellulose and has pit fields through which plasmodesmatal connection exist between the cells.**
- It **stores food material** and **other substances like resins, latex, mucilage** etc.
- The main function of phloem parenchyma is storage of food material and function of phloem rays (**ray parenchyma)** is **conduction of food in radial direction.**
- **Phloem parenchyma** is **absent** in most of the **monocotyledons**.
- The conducting element of phloem is called **Leptome.**
- **Leptome** term was given by **Haberlandt.**

5. Tissue System :



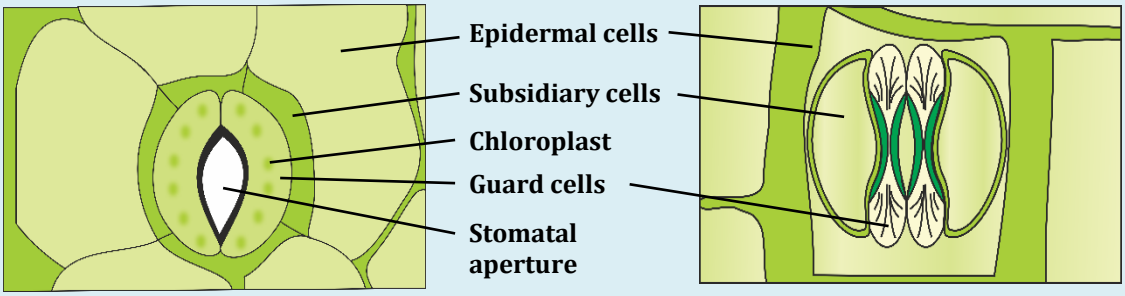
- In higher plants several tissues work together in the form of a unit to perform particular functions. These tissues have the same origin. Such tissues form a system which is called tissue system. On the basis of **Location/ position** & **structure / morphology** tissues were categorised by **Von Sachs** (German scientist) into three types of tissue system. Each system usually consists of an association of tissues which perform specific function:-

(1) Epidermal/Dermal Tissue System (E.T.S.) :

This system includes epidermis and its related structures.

e.g. Root hairs, trichomes, stomata etc.

Stomata :- Stomata are the structures present in epidermis of leaves and young stem. They regulate the process of transpiration and gaseous exchange.

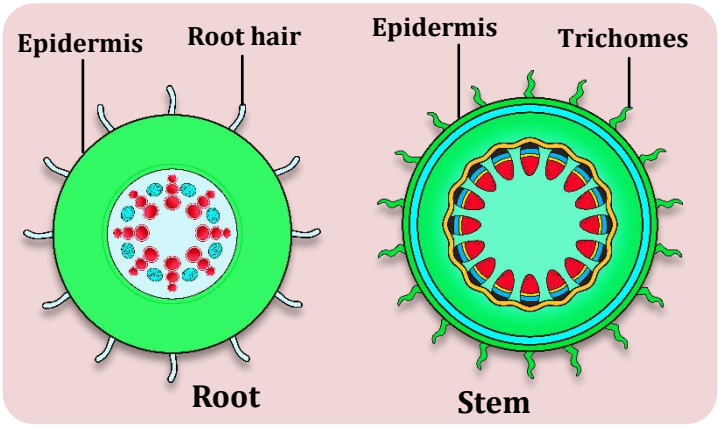


Diagrammatic representation:
(a) stomata with bean-shaped guard cells
(b) stomata with dumb-bell shaped guard cells.

TG: @Chalnaayaaar

- Each stoma is composed of two bean shaped (dicots) or dumbbell shaped (grasses) cells called as guard cells.
- Guard cells have elastic outer thin walls and elastic inner thick walls, they have chloroplasts and regulate. the stomatal movement. In the vicinity (surrounding) of guard cells generally by two or more subsidiary cells present. Between the two guard cells an opening is present known as **Stomatal pore or stomatal aperture.**
- **The stomatal aperture, guard cells and subsidiary cells are together called Stomatal Apparatus**
- **Trichomes :-** The cells of the epidermis give rise to a number of protuberances which vary markedly in their shape, structure and function. These are known as trichomes. These appendages can be unicellular or multicellular (usually) and elongated structures. On the other hand, the multicellular trichomes and glands are made up of several layers of cells.

  Note : In shoot system, **trichomes** are **usually multicellular.**
- **Function :** The trichomes help in reduction of water loss, due to transpiration.
- **Root hair :-** The root hairs are formed due to the elongation of the epidermal cells. These have a vacuolated protoplasm. The thin wall is made up of cellulose and pectic materials.
- **Root hairs** are always **unicellular**.



- **Function :** Root hairs play an important role in absorbing water from soil.
- **Epidermis :** It is outermost layer and made up of elongated, compactly arranged cells. It is usually single layered and made up of parenchymatous cells. Cuticle (Waxy thick layer) is present on the epidermis which prevents the loss of water. Cuticle is absent in roots.

(2) Ground Tissue System (G.T.S.) :

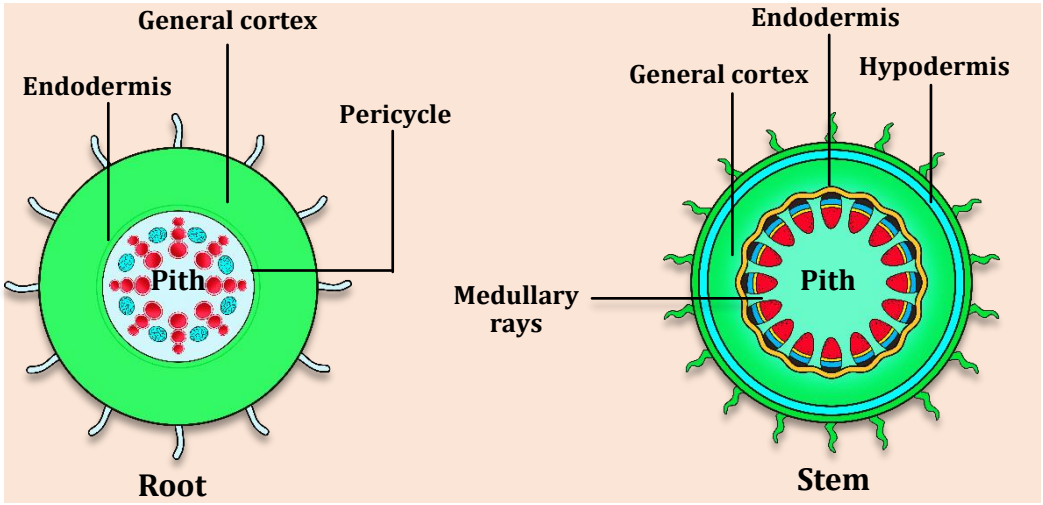
It is the **largest tissue system**. It includes hypodermis, general cortex, endodermis, pericycle and medullary rays (pith rays), pith. In leaf G.T.S. is consists of mesophyll. It is also called **fundamental tissue system.** It consists of simple tissues such as parenchyma, collenchyma & sclerenchyma.

Note :- Primary structure of plant organ is mainly composed of parenchyma.

Main functions :

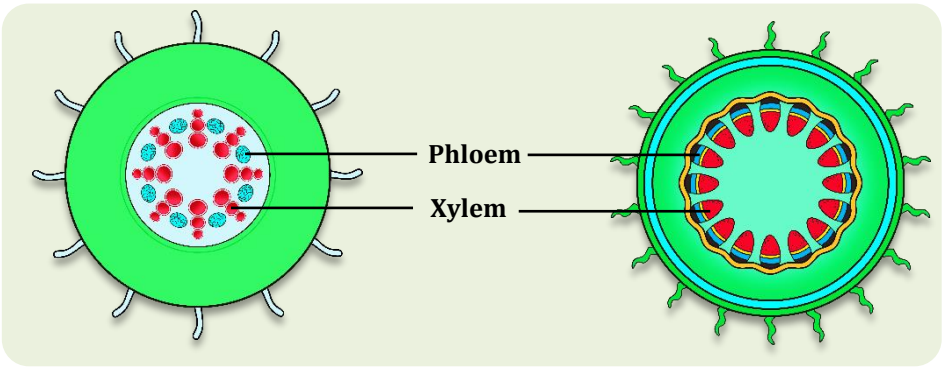
- Manufacture and storage of food material.
- Mechanical support (additional work)
- In roots pericycle produces lateral branches.
- Pith is very well developed in monocot roots and dicot stems.

TG: @Chalnaayaaar



(3) Vascular/Conducting Tissue System (V.T.S.) :

The V.T.S. consists of complex tissues, xylem and phloem.



Types of development of primary xylem :-

I. **Centrifugal** :- In this type of development, the protoxylem is formed towards the centre (pith) and metaxylem is formed away from the centre, it means towards the periphery. In this condition xylem is known as **endarch**. ***e.g.*** **Stem of angiosperms & gymnosperms**

II. **Centripetal** :- In this type of development protoxylem is formed towards the periphery (near the pericycle) and metaxylem is formed towards the centre. In this condition xylem is called **exarch**. ***e.g.*** **Roots**.

III. **Centrifugal and Centripetal** :- Elements of metaxylem are formed on both sides of the elements of protoxylem. In this type of development protoxylem is surrounded by metaxylem. In this condition xylem is known as **mesarch**. ***e.g.*** **Fern rhizome** (underground stem).

Vascular Bundles :

Xylem and phloem are collectively termed as vascular bundles.

Which may or may not have cambium.

Types of vascular bundles

On the basis of arrangement of their elements, vascular bundles are divided into three categories.

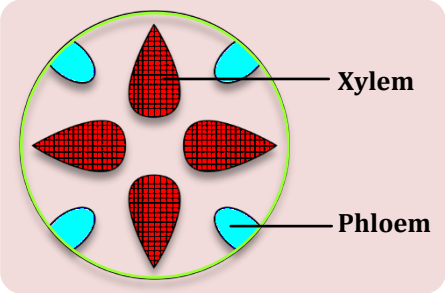
TG: @Chalnaayaaar

TG: @Chalnaayaaar

(i) Radial Vascular Bundles :

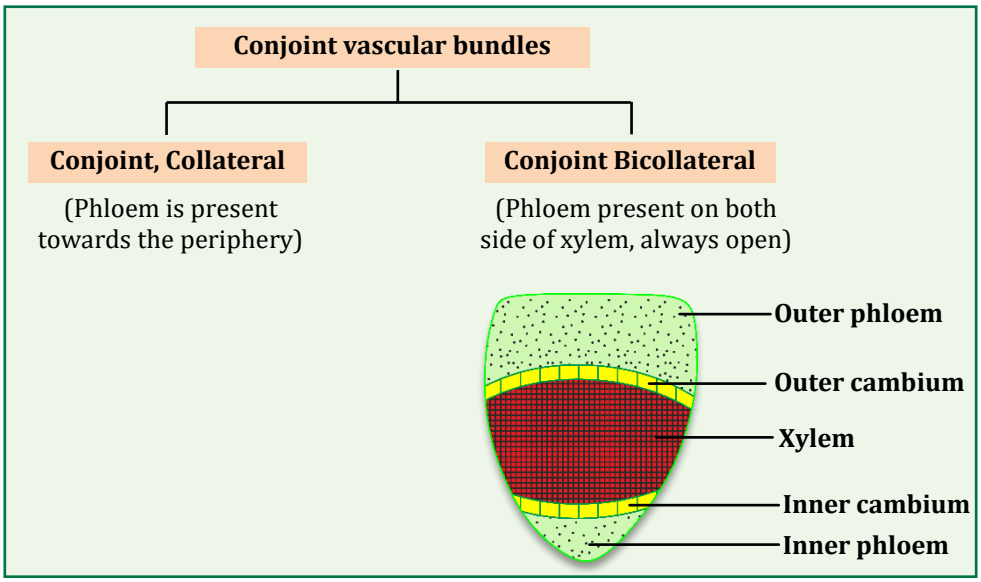
- When the xylem and phloem are present separately on different radii in alternate manner, then vascular bundles are called radial vascular bundles.
- In these vascular bundles **xylem is exarch.** The order of development of xylem in these vascular bundles is **centripetal**.

Example :- Most of the **roots**. (Dicot, monocot, gymnosperm, fern root)



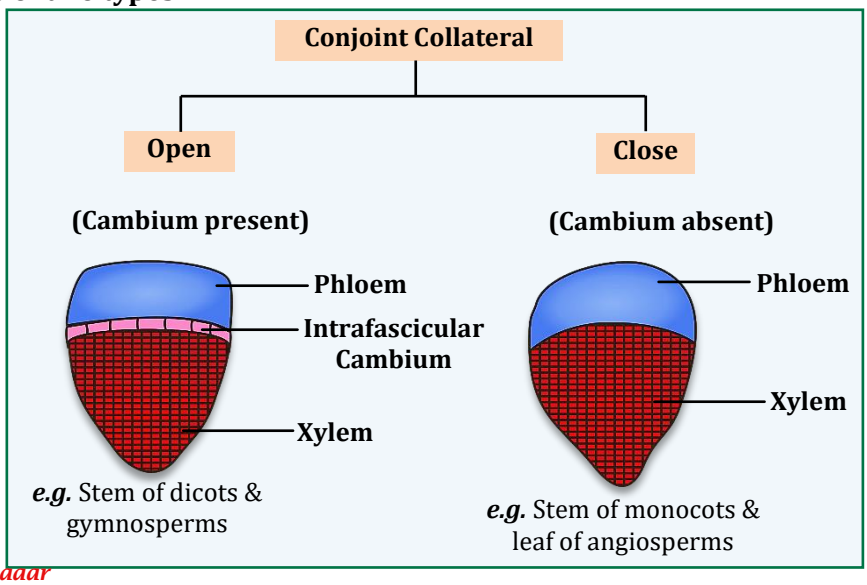
(ii) Conjoint Vascular Bundles :

- In these types of vascular bundles xylem and phloem are present on the same radius and combine into a bundle. These are of **two types** -



(a) Conjoint collateral : In this type of vascular bundle xylem and phloem are present on the same radius and phloem is present towards the periphery.

These are of two types -



TG: @Chalnaayaaar

(i) **Open** - If the cambium is present between the xylem and phloem, then it is said to be open vascular bundle. Ex. **stem of dicots/dicotyledons** and **gymnosperms**.

(ii) **Closed** - When cambium is absent between the xylem and phloem of conjoint vascular bundle then it is called closed vascular bundle.

Example. Monocotyledons stem, leaf of angiosperms.

In this type of vascular bundle, **xylem is endarch** and order of development of xylem is **centrifugal.**

(b) **Conjoint, bicollateral and open vascular bundle -** In this type of V.B. two patches of phloem, one on each side of xylem are found. There are two strips of cambium (outer and inner), one on each side of xylem are found. Only **outer cambium** is functional.

Order of development of xylem is **centrifugal** means **endarch** condition is found

Example. **stem of family cucurbitaceae** and some plants solanaceae.

(iii) **Concentric Vascular Bundles :**

- In these types of vascular bundles either xylem surrounds the phloem or phloem surrounds the xylem. Concetric vascular bundles are always **closed**. They are of two types -

(a) **Amphicribral or Hadrocentric** :

- In this type of vascular bundle xylem is completely surrounded by phloem. It means xylem is present in the centre of vascular bundle.
- The order of development of xylem in these vascular bundles is both **centripetal** and **centrifugal.**
- In these type of vascular bundles protoxylem is surrounded by metaxylem **(mesarch xylem)**
- Such types of vascular bundles are found in **ferns rhizome (Underground stem)**.

(b) **Amphivasal or Leptocentric :**

- In this type of vascular bundle phloem is completely surrounded by xylem. It means phloem is present in the centre of the vascular bundle.
- In this type of vascular bundle, xylem is **endarch**. ***e.g.*** stem of ***Dracaena, Yucca*** etc.

Golden Key Points

- **Meristos** is a Greek word which means **divided** or **dividing.**
- A simple tissue is made of only one type of cells whereas the complex tissues are made of more than one type of cells.
- Generally gymnosperms lack vessels.
- All tissues except epidermis and vascular bundles constitute the ground tissue.
- In the monocotyledons, the vascular bundles have no cambium, hence they are referred to as closed.

TG: @Chalnaayaaar

BEGINNER'S BOX-1 MERISTEM TO VASCULAR BUNDLES

1. The process of formation of secondary meristem from primary permanent tissue is called :-
(1) Differentiation (2) Dedifferentiation (3) Redifferentiation (4) Secretion

2. Which of the following are examples of primary lateral meristems :-
(1) Cork cambium and vascular cambium
(2) Interfascicular cambium and cork cambium
(3) Interfascicular cambium and vascular cambium
(4) Intrafascicular cambium and marginal meristem

3. Which of the following is primitive tissue :-
(1) Parenchyma (2) Collenchyma (3) Sclerenchyma (4) Xylem

4. Conjoint, collateral vascular bundles are found in :-
(1) Stems (2) Leaves (3) Roots (4) Both (1) & (2)

5. Phloem parenchyma is absent in :-
(1) Most of the Monocotyledonous stem (2) Most of the Dicotyledonous stem
(3) All Monocotyledonous stem (4) All Dicotyledonous stem

6. The location of apical meristems is :-
(1) Lateral sides of roots and shoots
(2) In between the vascular bundles
(3) At the tips of roots and shoots
(4) Between apex and mature areas of roots and shoots

7. Which of the following statements is incorrect for secondary meristems?
(1) They regenerate the parts of grasses damaged by grazers
(2) They are the cylindrical meristems
(3) They occur in the mature regions of roots and shoots
(4) They appear later than primary meristems in the life of a plant.

8. Tissue is :-
(1) Group of cells which are similar in origin and function
(2) Group of organs which are similar in origin and function
(3) Cells which are similar in function but not in origin
(4) Group of cells which are not similar in origin and function

9. All of the following statements are correct for cells of parenchyma except :-
(1) They are generally isodiametric
(2) They have lignified cell walls
(3) They may be spherical, oval, polygonal or elongated in shape
(4) They are the mature cells

10. Which of the following statements is correct?
(1) Angiosperms lack vessels in their xylem
(2) The presence of vessels in a characteristic feature of angiosperms
(3) The cells of vessels are living
(4) Vessels is a long cylindrical tube-like cell made up of many vessel members

TG: @Chalnaayaaar

11. Ground tissue of leaf is made of -
(1) Mesophyll (2) Sclerenchyma (3) Collenchyma (4) Vascular bundles

12. Which of the following is not a part of epidermal tissue system -
(1) Root hair (2) Stomata (3) Xylem (4) Trichome

13. **Assertion (A) :** Xylem and Phloem are complex tissues.
Reason (R) : Xylem and Phloem are made of many types of cells.
(1) Both (A) & (R) are correct and (R) is correct explanation of (A)
(2) Both (A) & (R) are correct but (R) is not correct explanation of (A)
(3) (A) is correct but (R) is incorrect
(4) Both (A) & (R) are incorrect

14. Find the incorrect about vascular tissue system –
(1) They include complex tissues (2) They include xylem and phloem
(3) They are generally present in stele (4) They are mainly made of one type of cells

6. Internal Structure of Dicotyledonous Root :

- Internal structure of a typical dicotyledon root shows following features :-

A. Epiblema/epidermis :

It is **uniseriate** (single layered) outermost layer. **Cuticle and stomata are absent**. **Many of the epidermal cells protrude in the form of unicellular root hairs means unicellular root hairs are formed due to elongation of cells of epiblema**. Root hairs are present in maturation zone of root. Root hairs are short lived.

Note : Cells of epiblema which develop root hairs are called **trichoblast cells**.
Hypodermis is absent in the roots.

B. Cortex :

It is made up of thin walled **parenchymatous** cells with intercellular spaces. Chloroplast is absent, so they are non-photosynthetic but chloroplasts are present in **roots of *Tinospora,*** and ***Trapa*** so they are **photosynthetic (Assimilatory) roots.**

C. Endodermis :

The innermost layer of the cortex is called endodermis. It comprises a single layer of barrel - shaped cells without any intercellular spaces. This layer of **barrel shaped cells** is situated between the pericycle and cortex.

Casparian strips/bands are present on radial and tangential walls of endodermis. These strips are made up of **ligno suberin means lignin & suberin (mainly suberin)**. Suberin is water impermeable waxy material. Casparian strips were discovered by **Caspari**.

- The cells of endodermis which are situated in front of protoxylem cells are devoid of casparian strips. These are called **passage cells/path cells.**
- Passage cells provide path to absorb water from cortex to pericycle.
- **Intercellular spaces are absent between the cells of endodermis of root.**
- **Endodermis** acts as a **water tight jacket** (Dam) which **prevents leakage of water from stele**.

TG: @Chalnaayaaar

D. Pericycle :

- It is a single or **few layers of thick walled parenchymatous cells** (It is composed of **prosenchyma**).
- **Lateral roots** usually originate from the part of pericycle which is lying opposite to protoxylem. Thus lateral roots are **endogenous** in origin.

Note : -

(i) The **branches of stems (vegetative branches)** are **exogenous** in origin because they originate from extrastelar region.

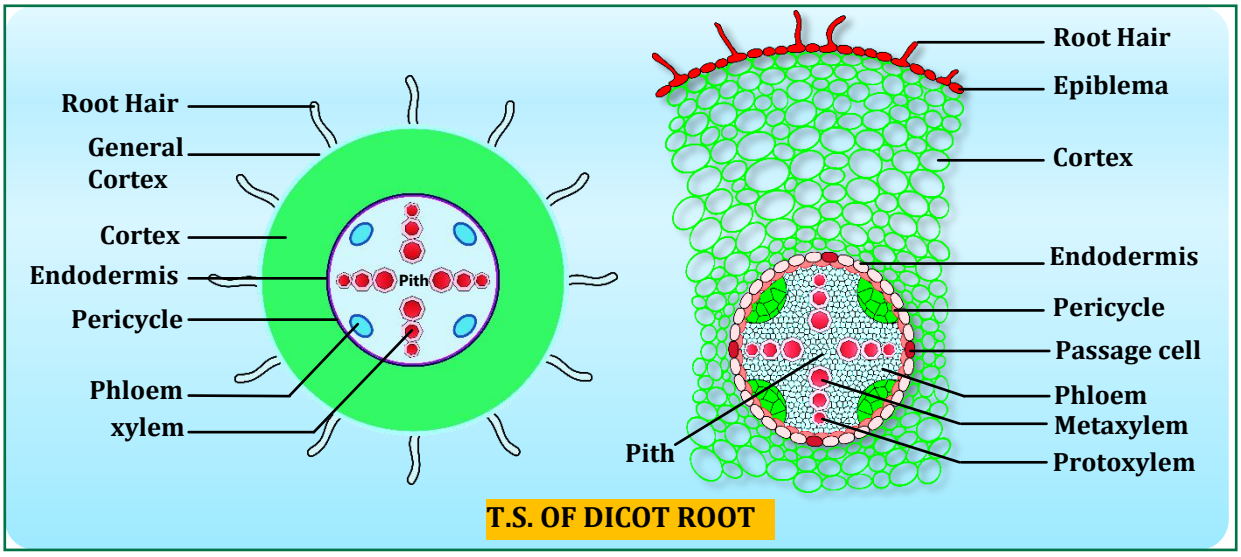
(ii) **Adventitious roots** are **endogenous** in origin because they originate from stellar region.

E. Vascular bundles :

- Vascular bundles are **radial** and **exarch**. xylem and phloem are separate and equal in number. The number of xylem patches and phloem patches are **usually two to four** but they may be two to six (diarch to hexarch). Tetrarch condition is found in gram & sunflower.
- Parenchyma which is found between the xylem and phloem is called **conjunctive tissue.**
- **In dicot root xylem vessels appear angular (polygonal/hexagonal) in T.S.**

F. PITH :

In dicot root pith is **small (less developed)** or **inconspicuous** or absent.



T.S. OF DICOT ROOT

7. Internal Structure of Monocotyledonous Root :

- The internal structure of a typical monocotyledon root is similar to dicotyledon root except some differences which are as follows :-
  - **(1)** Number of **xylem bundles** are **usually more than six (polyarch)** in monocotyledon root.
  - **(2)** **Pith** is **large and well developed** in monocotyledon root
  - **(3)** **Xylem vessels** appear **circular or oval** in T.S.
  - **(4)** Monocotyledonous roots do not undergo secondary growth.

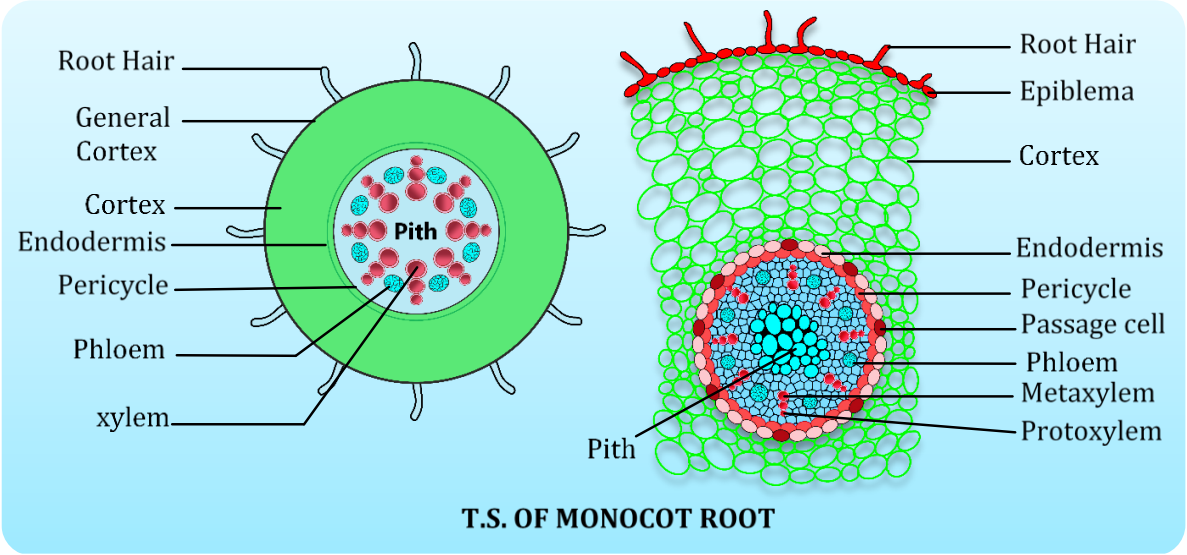
Note : As the epiblema dies off (in old roots), a few outer layers of the cortex become **suberized** (mainly) or cutinized and form the **exodermis**. Exodermis is usually found in monocot roots.

TG: @Chalnaayaaar

Velamen :- This spongy tissue is found in aerial roots or hanging roots of epiphytes.

e.g. **Orchids, *Vanda***

- It is an example of **multilayered epidermis**
- It **absorbs atmospheric moisture** by imbibition.



T.S. OF MONOCOT ROOT

8. Internal Structure of Dicotyledonous Stem:

Internal structure of a typical dicot (dicotyledonous) stem shows following features :-

A. Epidermis :

- Epidermis is the outermost protective layer of the stem. It is made up of elongated compactly arranged cells. It is **single layered** and lack of chloroplasts.
- Stomata, **multicellular hairs (trichomes)** are present on epidermis. Thin **cuticle** is present on epidermis.
- Epidermis plays a significant role in protection.
- Trichomes help in preventing water loss due to transpiration.

B. Cortex :

The cells arranged in multiple layers between epidermis and pericycle constitute the cortex. In dicotyledon stem cortex is divided into three parts or sub zones.

(a) Hypodermis
(b) General cortex
(c) Endodermis

(a) Hypodermis : It is present just below the epidermis. It is multilayered thick. It is composed of collenchyma and cells often contain **chloroplasts.**

(b) General Cortex : This part is composed of rounded thin walled cells of **parenchyma** with conspicuous intercellular spaces. Storage of food is the main function of the cortex. Resin canals/mucilage canals are present in it. These are schizogenous in origin. The innermost layer of the cortex is called **endodermis**.

(c) Endodermis : It is single layered. The cells of endodermis are rich in starch grains, thus it is also known as **"starch sheath".**

TG: @Chalnaayaaar

C. Pericycle :

- Pericycle is situated below the endodermis. The pericycle of stem is multilayered.
- In **sunflower** stem, **pericycle** is made of alternate bands of **parenchymatous** and **sclerenchymatous** cells. The part of pericycle which is present infront of the vascular bundle is made up of sclerenchyma and remaining part is composed of parenchyma. Part of pericycle which is situated in front of vascular bundle is known as **Bundle cap**. In sunflower stem, pericycle is **heterogenous** in nature. Sclerenchymatous part of pericyle is also known as **Hard bast.**

Note :- **Pericycle is present above the phloem in the form of semilunar patches of sclerechyma.**

D. Vascular bundles :

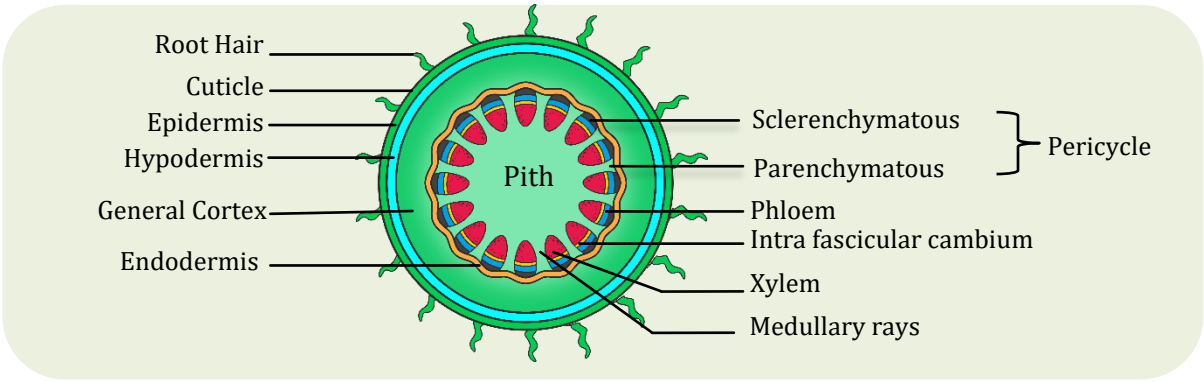
The **wedge-shaped** vascular bundles are **arranged in a ring**. The ring arrangement of vascular bundles is a characteristic of dicot stem. Each vascular bundle is **conjoint, collateral** and **open** and **xylem is endarch.**

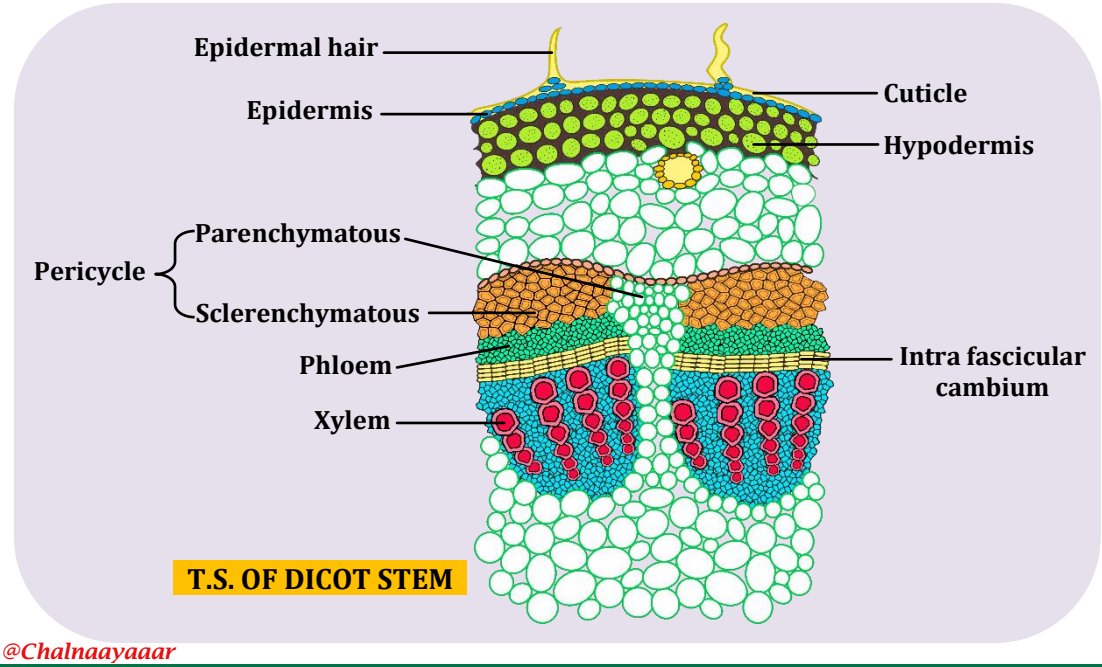
A layer of primary lateral meristem i.e. intrafascicular cambium is present in each vascular bundle.

E. PITH :

This is well developed region, present in the centre. The cells of this region are of parenchymatous.

F. Medullary Rays : -Radially arranged parenchymatous cells in between the vascular bundles, called **pith rays or medullary rays**. The main function of pith rays is radial conduction of food and water.





TG: @Chalnaayaaar

9. Internal Structure of Monocotyledonous Stem:

A. Epidermis : Epidermis is the outer most single celled thick layer. It is covered with thick cuticle. **Multicellular hairs are absent.**

B. Hypodermis : Hypodermis of monocotyledon stem is **made up of sclerenchyma**. It is 2-3 layered thick. In monocot stem rigidity is more in hypodermis whereas in dicot stem elasticity is more. It provides **mechanical** support to the plant.

C. Ground Tissue : It is large, conspicuous parenchymatous. There is no differentiation of ground tissue in monocotyledon stem. It means ground tissue is **not differentiated into general cortex, endodermis, pericycle, pith & medullary rays**.

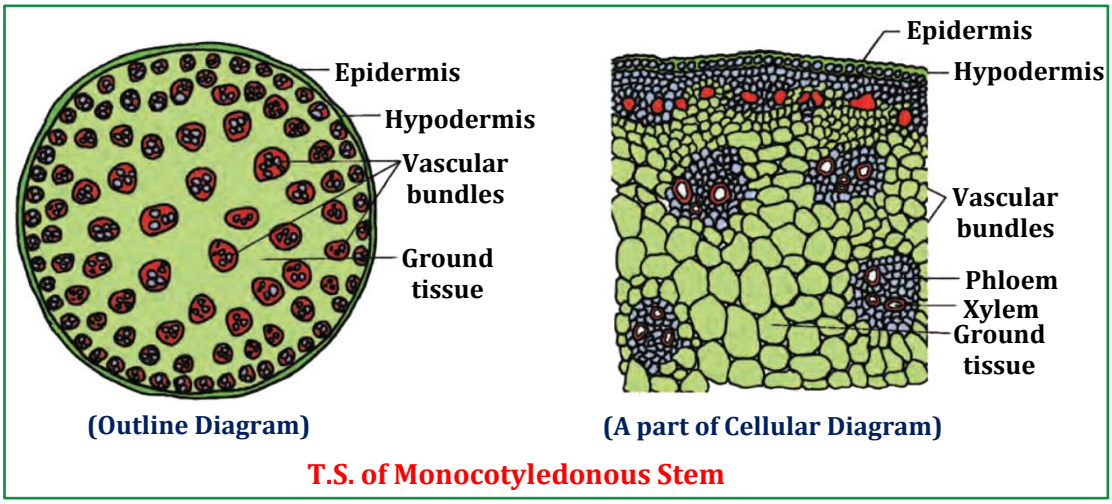
Note : Sometimes in some grasses, wheat etc. the central portion of ground tissue becomes hollow and is called **pith cavity** e.g. stems of *Cucurbita*.

D. Vascular Bundle (V.B.) : Many vascular bundles are found **scattered** in the ground tissue and V.B. are generally oval (egg shaped). Peripheral vascular bundles are generally smaller than the centrally located ones. Vascular bundles which are situated towards the **centre** are **large** in size and **less** in number. Peripheral vascular bundles are **small** in size but **more** in number. Each vascular bundle is **conjoint, collateral and closed** and **xylem is end arch**. Each vascular bundle is surrounded by **sclerenchymatous bundle sheath**. so, vascular bundles are called **fibro vascular bundles**. Water containing cavities are present within the vascular bundles.

(a) Xylem :- In xylem number of **vessels** is less. In **metaxylem** there occurs **two large vessels** while in **protoxylem** there occurs **one** or **two small vessels**. Vessels are **arranged** in the form of **V or Y**.

Just beneath protoxylem vessels, there occurs a **water cavity** which is **schizolysigenous** in origin. In which major part of water cavity is **lysigenous** in origin (formed due to lysis of protoxylem elements) and few part of water cavity is schizogenous (formed by separation of cells).

(b) Phloem :- It consists of sieve tube elements and companion cells. **Phloem parenchyma** is absent.



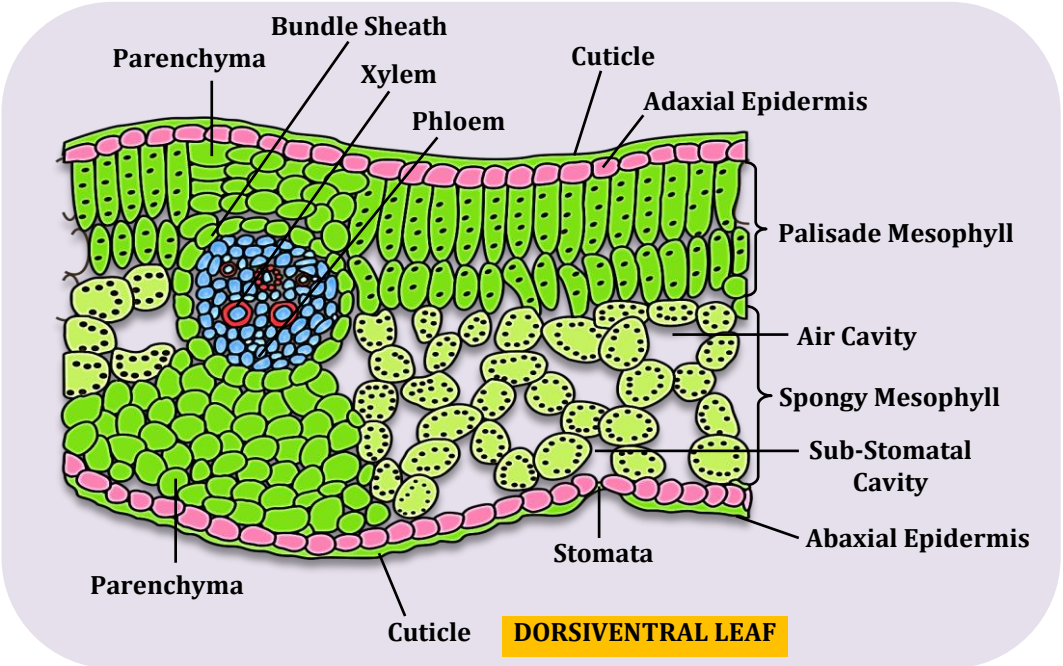
(Outline Diagram) (A part of Cellular Diagram)

T.S. of Monocotyledonous Stem

TG: @Chalnaayaaar

10. Internal Structure of Dorsiventral (Dicotyledonous) Leaf :

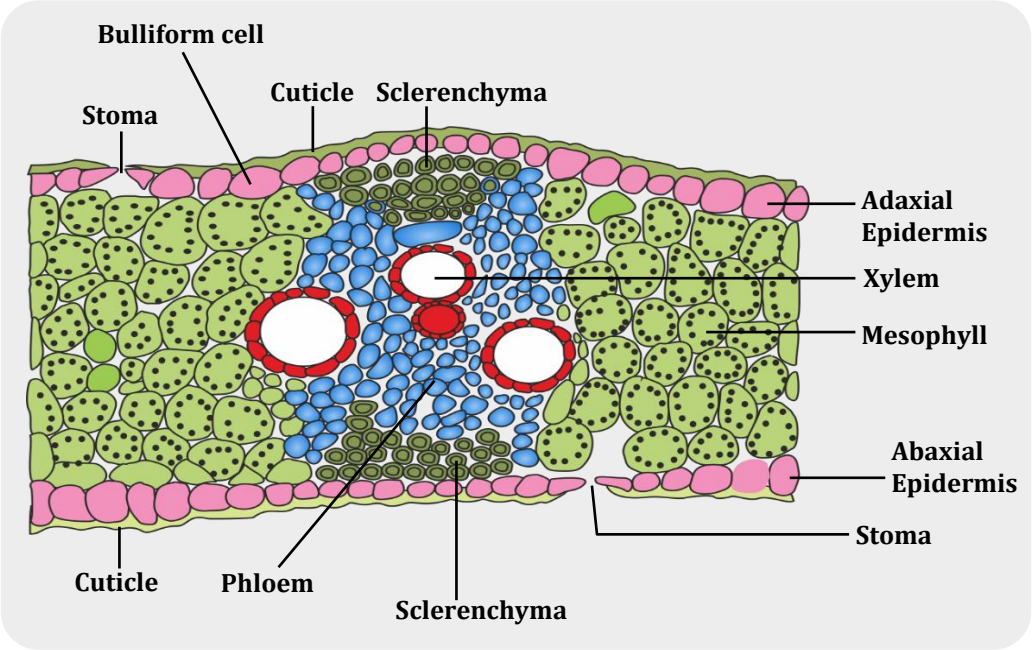
- Generally, leaves are divided into **two categories** - Dorsiventral leaves and isobilateral leaves.
- Cuticle is present on both surfaces but **cuticle on upper surface is more thick**.
- In dorsiventral leaves **stomata are more on lower surface** and stomata on upper surface are absent or less in number.
- The tissue between the upper & the lower epidermis is called the mesophyll.
- **In dicot leaf, mesophyll is differentiated** into **palisade** parenchyma (palisade mesophyll or palisade tissue) and **spongy** parenchyma (spongy mesophyll or spongy tissue).
- **Palisade tissue** is situated towards the upper (adaxial or ventral) surface. It is made up of elongated cells which are arranged vertically and parallel to each other and have more chloroplasts and a large vacuole.
- **Spongy tissue** is situated towards lower (abaxial or dorsal) surface. The cells are oval or rounded and between the cells large air spaces / air cavities are present.



11. Internal Structure of Isobilateral (Monocotyledonous) Leaf :

- The **thickness of cuticle is equal** on both surfaces.
- Usually **stomata on both surfaces** are **equal** in number.
- **Mesophyll is not differentiated** into palisade and spongy tissues in isobilateral leaves. Mesophyll cells have only a few intercellular spaces.

TG: @Chalnaayaaar



Note :-

(1) In **isobilateral leaf**, two distinct patches of **sclerenchyma** are present above and below the large vascular bundle and extend up to the upper and lower epidermal layers. These are called bundle sheath extensions.

(2) In **dorsiventral leaf**, two distinct patches of **parenchyma (mainly)**/collenchyma are present above and below the large vascular bundle and extend up to the upper and lower epidermal layers. These are called bundle sheath extensions. Chloroplasts are absent in bundle sheath extensions.

Vascular Bundles of Leaves :

- Similar types of vascular bundles are
- found in both dorsiventral and isobilateral leaves. Vascular bundles of leaves are **conjoint, collateral** and **closed**.
- **Protoxylem** is situated **towards the adaxial** (upper) surface and **protophloem towards the abaxial** (lower) surface in the vascular bundle. Leaves are **devoid** of **endodermis** and **pericycle**.
- Vascular bundles are surrounded by a **bundle sheath**. It is made up of thick-walled **parenchyma**.

Note :

1. In the leaves of **C_4-plants** (***e.g.*** sugarcane, maize etc.) **bundle sheath is chlorenchymatous**.

2. **In grasses**, certain adaxial epidermal cells along the veins modify themselves into large, empty, colourless cells. These are called **bulliform cells** or **motor cells**. When the bulliform cells in the leaves have absorbed water and are turgid, the leaf surface exposed. When they are flaccid due to water stress, they make the leaves curl inwards to minimise water loss.

3. **The stomatal aperture, guard cells and the surrounding subsidiary cells are together called stomatal apparatus**.

4. **The size of vascular bundles is dependent on the size of the veins. The veins vary in thickness in the reticulate venation of the dicot leaves**.

5. **The parallel venation in monocot leaves is reflected in the near similar sizes of vascular bundles (except in main veins) as seen in vertical sections of the leaves**.

TG: @Chalnaayaaar

TG: @Chalnaayaaar

12. Secondary Growth :

- By the activity of lateral meristems (vascular cambium and cork cambium), **increase in the circumference / girth / thickness** of the plant organs is called secondary growth.
- Normally secondary growth takes place in **roots and stem of dicotyledons** and **gymnosperms**.
- The tissues involved in secondary growth are two lateral meristems: vascular cambium and cork cambium.
- Secondary growth is not found in the leaves and monocots.
- Due to lack of cambium in monocotyledons, secondary growth is absent. But **exceptionally** secondary growth takes place in **some monocotyledons**. Such as - ***Palm, Date Palm, Coconut Palm, Yucca, Dracaena,*** *etc.* These plants show **abnormal secondary growth**.

(1) Secondary Growth in Dicot Stem :

(a) Secondary Growth in Stelar Region by Vascular Cambium :

Secondary growth in stelar region begins earlier than the extrastelar region.

I. Formation of ring of vascular cambium :

- A cambium which is present inside the vascular bundle (means between primary xylem and primary phloem) is called **intrafascicular- cambium**. This is a type of primary lateral meristem.
- First of all, cells of medullary rays adjoining intrafascicular cambium become meristematic to form **interfascicular cambium** which is a secondary lateral meristem.
- Intrafascicular and interfascicular cambium are collectively known as **vascular cambium** or intra stelar cambium. Vascular cambium is formed in the form of a complete ring which is made up of single layer of cells.
- In diocot stem, the **vascular cambium is partly primary and partly secondary** in origin.
- Two types of cells are found in the ring of this vascular cambium.
  (i) Fusiform initials **(ii) Ray initials**.
- Fusiform initials are long with pointed ends, whereas ray initials are spherical/rounded or oval in shape.
- Fusiform initials are more in number in vascular cambium.

II Activity of vascular cambium :

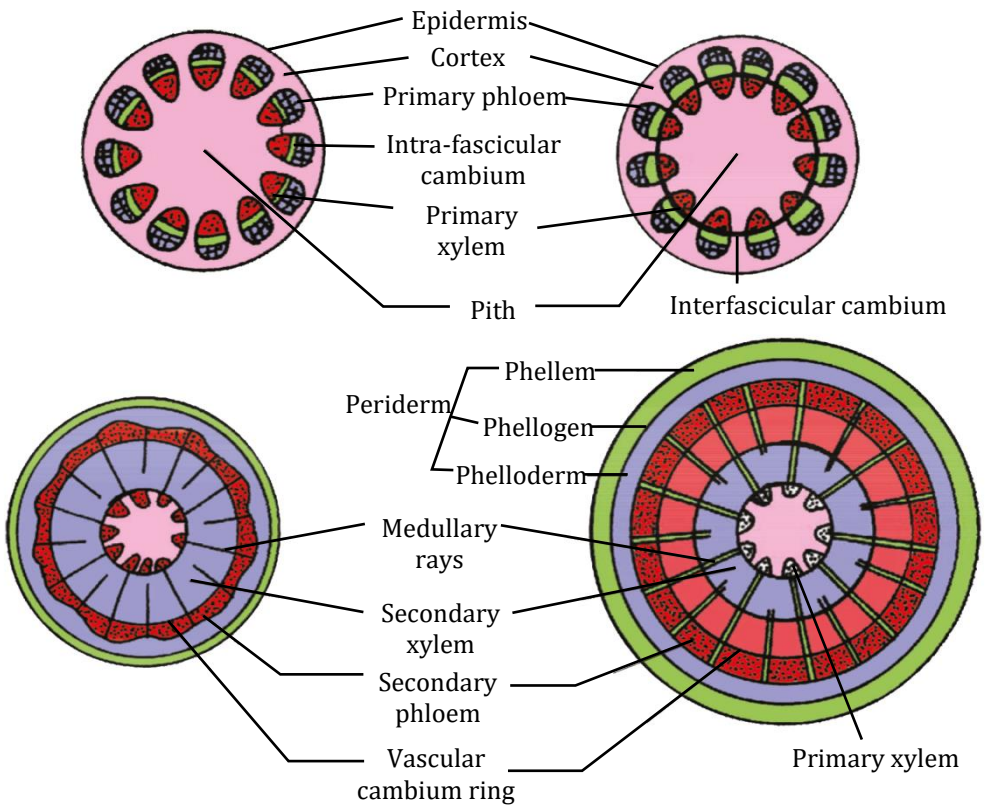
(a) Activity of fusiform initials :

- Continuous periclinal divisions (parallel to longitudinal axis) takes place in fusiform initials, then few cells are formed towards the periphery which differentiate into **secondary phloem or bast** and the cells which are formed towards the centre (towards pith) get differentiated into **secondary xylem or wood**.
- The cambium is generally more active on the inner side than on the outer.
- Normally **more secondary xylem** is formed as compared to the secondary phloem **due to unequal distribution of hormones**. (**Secondary xylem** is formed **8-10 times more** as compared to the sec. phloem).
- By the pressure of secondary xylem, all the primary tissues- such as **primary xylem, pith** are pushed towards the centre.
- The **primary xylem** however remains **more or less intact** in or around the centre. The primary phloem and earlier secondary phloem (old secondary phloem) get gradually crushed due to the continued formation and accumulation of secondary xylem.

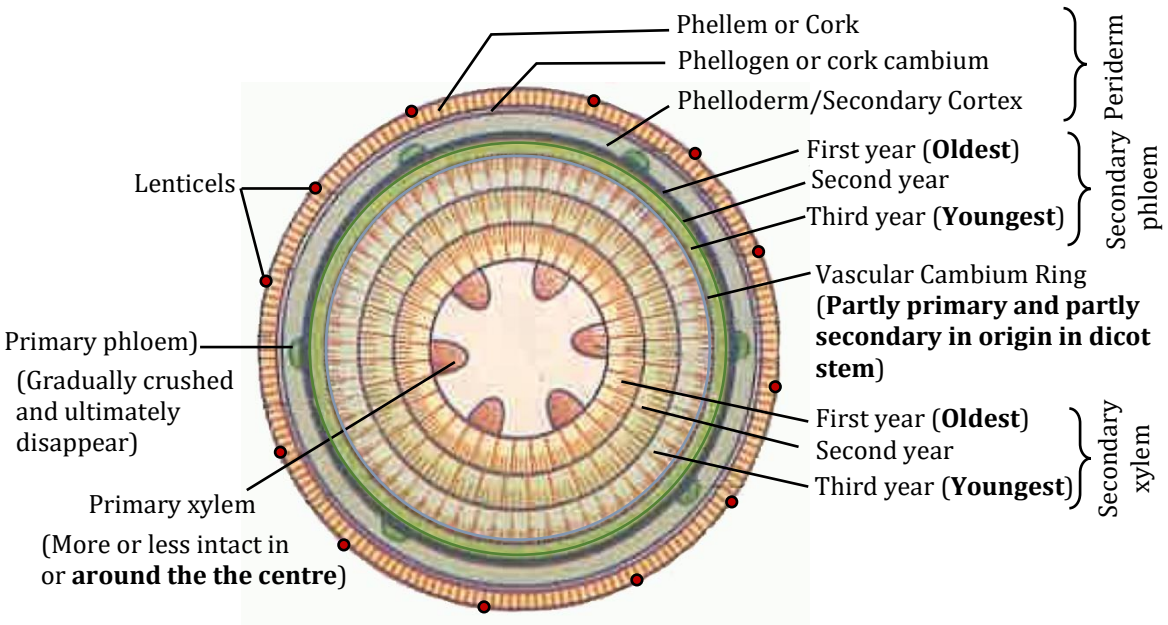
(b) Activity of Ray initials :- Due to periclinal divisions ray initials cuts off (form) parenchymatous cells. These are called **vascular rays** (Xylem rays and phloem rays) or **secondary medullary rays** which passes through the secondary xylem and secondary phloem in the radial direction. They

TG: @Chalnaayaaar

conduct water and **food** in **radial direction**. The order of development of vascular rays are both centripetal and centrifugal.



Secondary growth in a dicot stem (diagrammatic) – stages in transverse views



T.s. of Woody dicot stem showing secondary growth in stelar and extra stelar regions

***** Primary phloem and earlier secondary phloem get gradually crushed due to the continued formation and accumulation of secondary xylem.**

TG: @Chalnaayaaar

TG: @Chalnaayaaar

III. Formation of Annual Rings :

- Annual rings are formed due to unequal activity of vascular cambium.
- The activity of cambium does not remain same, it is changeable in the whole year.
- **Activity of vascular cambium is under the control of many physiological and environmental factors.**
- In temperate regions, the climatic conditions are not uniform through the year.
- In the spring season, vascular cambium is very active and produces a large number of secondary xylem elements having vessels with wider cavities / lumens. The wood formed during this season is called **spring wood** or **early wood.**
- In winter and autumn season, the vascular cambium is less active and forms fewer secondary xylem elements that have vessels with narrow lumen and this wood is called winter wood or **autumn wood** or **late wood.**
- **The spring wood is lighter in colour and has a lower density whereas the autumn (or winter) wood is darker and has a higher density.**

Note :

(1) The **autumn** and **spring wood** are formed in the form of concentric rings, called **growth rings**. The two kinds of woods that appear as alternate concentric rings, constitute an annual ring.

(2) A **ring of autumn wood** and a **ring of spring wood** are collectively known as **Annual ring**. The number of annual rings, formed in a tree give the idea of the age of the tree. The study of determination of age of a tree/plant by counting annual rings is called **Dendrochronology**.

(3) The annual rings are counted from the **base of the stem** because basal part has maximum annual rings and upper part has less. Therefore, counting from the basal region can give the correct idea.

(4) A piece of wood is taken from the stem up to central region from the base of stem with the help of **increment borer** instrument. The annual rings are counted from that piece and again inserted (fitted) into the same stem at the same place.

(5) More distinct/clear annual rings are formed in that regions where climatic variations are sharp.

(6) **More distinct annual rings** are formed in **temperate plants**. Because in temperate regions, the climatic conditions are not uniform throughout the year.

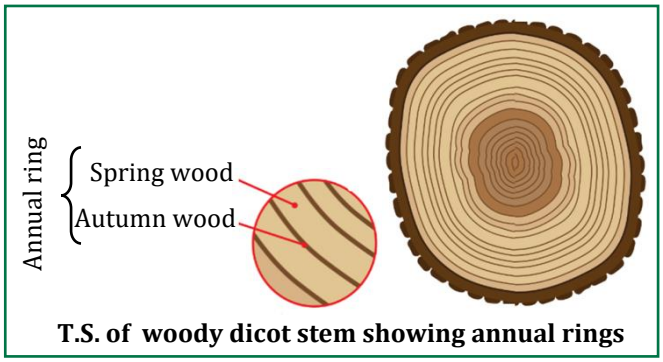
(7) Distinct annual rings are not formed in tropical plants. **Distinct/clear annual rings are not formed in India except Himalayan regions (Shimla, Nainital etc.).**

(8) Least distinct annual rings are formed in seashore regions/coastal regions because the climate remains the same throughout the year.

(9) More clear annual rings are formed in deciduous plants as compared to evergreen plants. (In temperate region)

(10) In deserts annual rings are less distinct.

(11) In **annual rings bands of secondary xylem and xylem rays (Ray parenchyma) are present.**

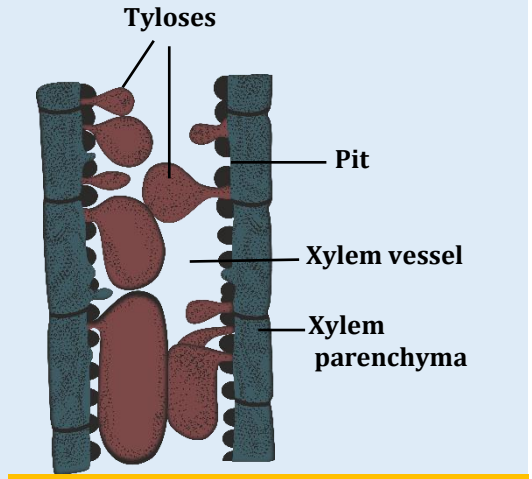


T.S. of woody dicot stem showing annual rings

TG: @Chalnaayaaar

Heart Wood and Sap Wood :

- In old trees, the greater part of secondary xylem is dark brown.
- The organic compounds like tannins, resins, gums, oils and aromatic substances etc. are filled in lumen of tracheids and vessels of secondary xylem. Due to this, **central region** of secondary xylem becomes **dark brown**. It is called **heart wood or duramen**. These substances make it hard, durable and resistant to the attack of micro-organisms and insects. Heart wood comprises dead elements with highly lignified walls. Heart wood provides mechanical strength to stem.
- The **peripheral region** of secondary xylem which is **light** in colour, is called **sap wood or alburnum**.
- The function of sap wood is conduction of water and minerals.



L.S. of sec. xylem vessel showing tyloses

Heart wood does not conduct water because :-

1. Cavities of tracheids and vessels are progressively filled with waste materials.
2. The bladder/balloon like ingrowth of parenchyma cells enter in the lumen of vessels (mainly) & tracheids through the pits. Such bladder like ingrowths are called **tyloses** or tracheal plugs. Tyloses block the **lumen** of tracheary elements (vessels & tracheids).

- Heart wood provides stiffness to the stem. The waste materials of heart wood are **antiseptic** in nature. Heart wood is resistant to the attacks of termites and insects and in rainy season it does not imbibe water. Thus, it is the best quality of wood.
- Study of wood is known as **Xylology**. The wood is actually a **secondary xylem**.
- Position of youngest secondary phloem is just outside the vascular cambium.
- Position of oldest secondary phloem is just inside the primary phloem.
- Position of youngest layer of secondary xylem is just inside the vascular cambium.
- Position of oldest layer of secondary xylem is just outside the primary xylem.
- As the time passes amount of heart wood increases more as compared to sap wood.

(A) Classification of wood :

On the basis of **amount of parenchyma** wood is classified into two groups :-

1. **Manoxylic wood** :- Such type of wood contains **more amount of living parenchyma**. It is loose wood. ***e.g.*** *Cycas*.
2. **Pycnoxylic wood** :- Such wood contains **less amount of living parenchyma**.
   Example :- *Pinus (Conifers)*

(B) Classification based on vessels :-

On the basis of presence or absence of vessels, wood is classified into two categories -

1. ***Non-porous wood*** **/ Homoxylous wood** *:-* **Vessels are absent** in this type of wood.
   Example :- **Mostly gymnosperms**

TG: @Chalnaayaaar

2. ***Porous wood*** **/ Heteroxylous wood** *:-* **Vessels are present** in this type of wood. ***e.g.*** **Mostly dicots (Angiosperms)** On the basis of arrangement of vessels porous wood is divided into two groups.
   - **I. Ring porous wood** *:-* Vessels are arranged in the rings. ***e.g. Dalbergia***
   - **II. Diffused porous wood***:- Asystematical* distribution of vessels is found in this type of wood. ***e.g. Azadirachta (Neem).***
   - **Most durable wood ⟶ *Tectona grandis* (Teak = Sagwan)**

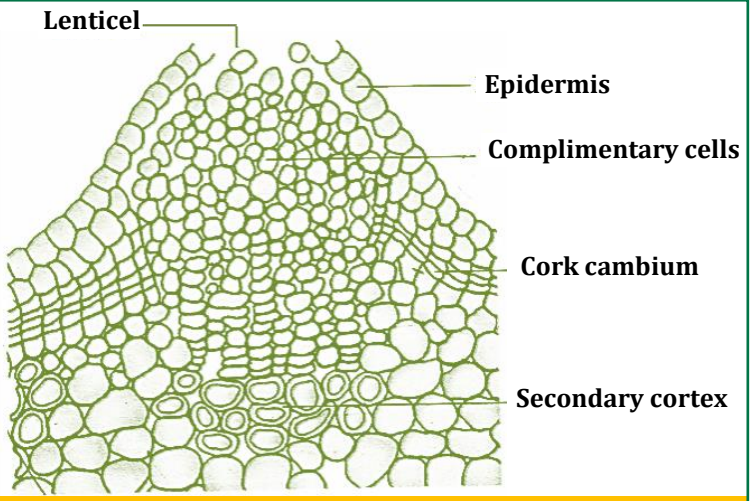
(b) Secondary Growth in Extra Stelar region by Cork Cambium :

- Secondary growth takes place in extra stelar region **due to the activity of cork cambium**. Cork cambium is also known as **phellogen** or **extrastelar cambium**. The cells of the cork cambium are narrow, thin walled and nearly rectangular. Cork cambium develops usually in cortical region by hypodermis.
- As the stem continues to increase in girth due to activity of vascular cambium the outer cortical & epidermal layers get broken & need to be replaced to provide new protective cell layers Hence sooner or later another meristematic tissue called cork cambium or phellogen develops.
- Cork cambium is derived from the **hypodermis (outer part of cortex)** by dedifferentiation. Cork cambium is **single** or **a couple of layers thick (mainly)**. It forms secondary tissues in extra stelar region.
- Cork cambium divides usually by periclinal division to form some cells towards the outside (towards epidermis) and some cells towards the inside (towards general cortex). Those cells which are formed towards outside, become suberized. Due to this, these cells become dead. These dead cells are known as **cork or phellem**. Those cells which are formed towards the inside, are differentiated into parenchyma and may contain chloroplasts. These are called **secondary cortex or phelloderm**.
- **Phellem, phellogen and phelloderm are collectively known as periderm.**
- The **cork is impervious to water** due to **suberin deposition** in the cell wall.
- **Commercial cork** is obtained from ***Quercus suber*** **(oak)**. Common bottle cork is made from this cork.
- Cork is formed in high quantity and secondary cortex is in less quantity because activity of cork cambium is more towards outside.
- Due to activity of the cork cambium, pressure builds up on the remaining layers peripheral to phellogen and ultimately these layers die and slough off.
- Cork cambium remains living and active only for one year. **Each year, a new cork cambium is formed** below the previous cambium. This new cambium is derived from the secondary cortex or phelloderm.
- **All the tissues which occur outside the innermost cork cambium are collectively termed as rhytidome**. Rhytidome includes cork and tissues which become dead due to the pressure of cork.

TG: @Chalnaayaaar

Lenticels :

- At certain regions, the phellogen (cork cambium) cuts off/forms closely arranged parenchymatous cells on the outer side instead of cork cells. These thin walled, rounded, colourless, parenchymatous cells are called complementary cells. These cells are **not suberized.** As the complementary cells increase in number, pressure is exerted on the epidermis due to which it ruptures, forming a lens-shaped opening called **lenticels.**
- Complementary cells are formed by the activity of **phellogen** (cork cambium).
- Lenticels are found in most of the woody trees.
- Lenticels are mainly **found on woody stems** and they are **never found** on **leaves**. They are also present on some **fruits**.
- Lenticels are not found in herbaceous dicots and monocot plants.



Transverse section of stem passing through a lenticel

Bark

Functions :

1. **Exchange of gases :** Lenticels permit the exchange of gases between the outer atmosphere and the internal tissue of the stem (main function).
2. **Help in transpiration** i.e., Lenticular transpiration.

Bark :- There are two views about the bark.

1. **Old view :-** All the tissues situated outside the cork cambium are called bark. According to old view bark includes mainly dead tissues.
2. **Modern view :- Bark** is a non-technical term that refers to **all tissues exterior to the vascular cambium**, therefore including secondary phloem. According to modern view bark includes both living and dead tissues.

Kinds of bark :

1. **Ring Bark = Sheet bark** :- Continuous bark of equal thickening is called ring bark. It is formed around the stem in the form of a complete ring. When **cork cambium is continuous** then ring bark is formed.

   Example :- **Bhojpatra (*Betula utilis*)** - A complete distinct ring bark is formed in this plant. Its bark was used as a writing material /as a paper in ancient period, only cork layer was used. Ring bark is also formed in ***Eucalyptus***.

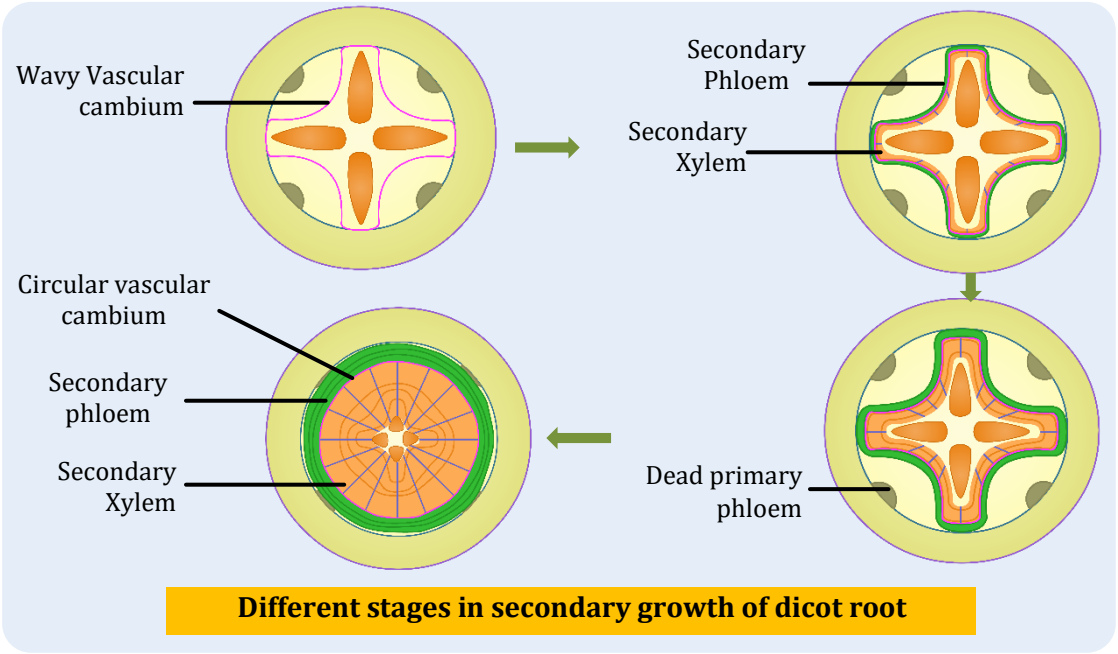
TG: @Chalnaayaaar

2. **Scaly Bark** :- Discontiuous bark of unequal thickening is called scaly bark. This bark is formed around the stem in the form of **pieces** or **fragments** or **patches**. When **cork cambium is discontinuous** then scaly bark is formed. ***e.g.*** Guava. Neem, Mango and *Tamarind* etc.

- Highly distinct scaly bark is formed in *Psidium guajava* (Guava)
- **Scaly bark is found in most of the woody plants.**
- **If bark is removed in the form of a ring (Girdling) from the base of main stem then root dies first due to lack of food.**
- **Girdling is not possible is monocot stem because vascular bundles are scattered.**
- **If complete bark is removed then plant dies due to excessive water loss.**
- **Bark that is formed early in the season is called early or soft bark. Towards the end of the season late or hard bark is formed.**
- **Secondary phloem and periderm are included in bark.**

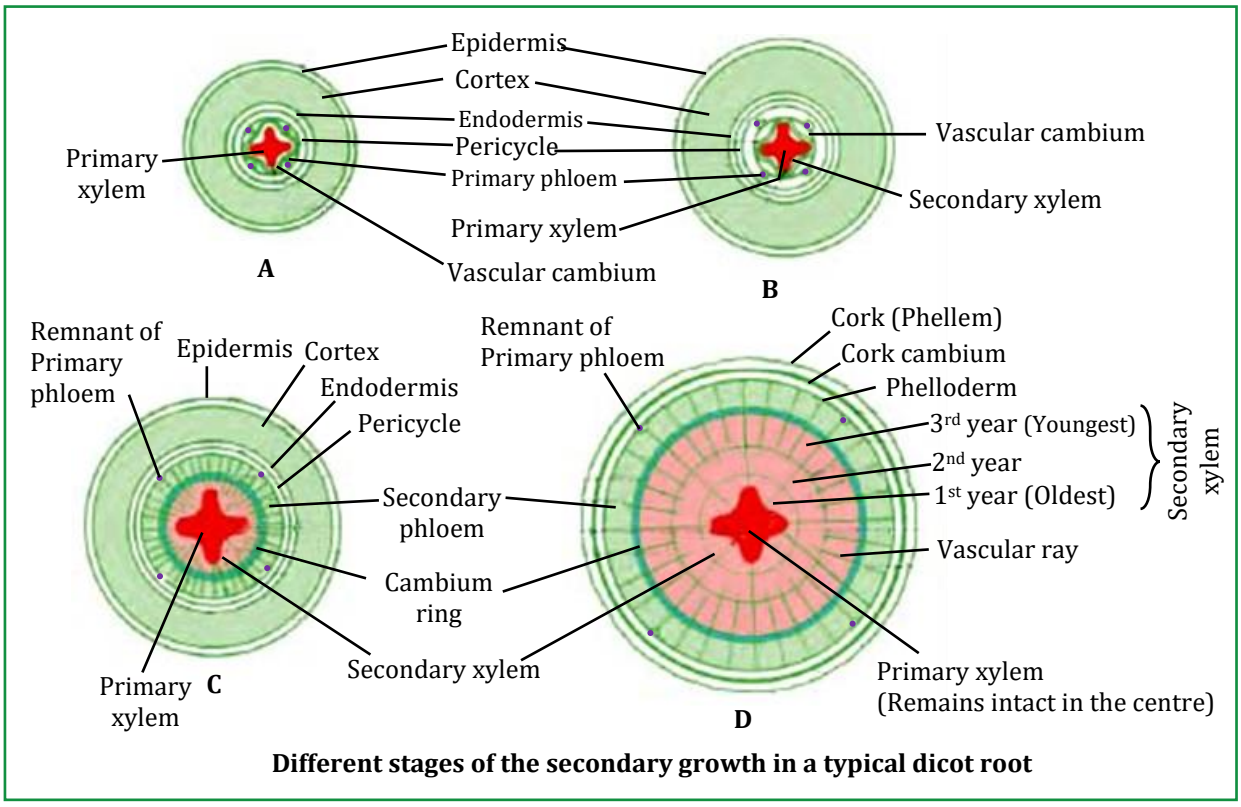
(2) Secondary Growth in Dicot Root :

- **In the dicot root, the vascular cambium is completely secondary in origin.**
- First of all, the tissue located just below the phloem bundles means **conjunctive tissue** becomes meristematic during the secondary growth in a dicotyledon root and forms separate curved strips of vascular cambium below the phloem bundles. Then after, the **cells of pericycle lying above the protoxylem** also become meristematic to form additional strips of cambium. In this way a complete wavy ring of vascular cambium is formed.
- The portion of vascular cambium which is formed by pericycle is less. The main portion of vascular cambium is formed by conjunctive tissue.
- The shape of **vascular cambium** is **wavy in the beginning**, but later on it becomes circular due to the pressure of secondary xylem. The portion of vascular cambium formed by conjunctive tissue divide first and forms the secondary xylem towards the centre. Ultimately the cambium becomes circular by the pressure of secondary xylem.



Different stages in secondary growth of dicot root

TG: @Chalnaayaaar



Different stages of the secondary growth in a typical dicot root

- The activity of vascular cambium of root is the same as the activity of vascular cambium of stem. **Secondary xylem** is formed towards the inner side and **secondary phloem** is formed towards the outer side by vascular cambium. The portion of vascular cambium which is formed by pericycle is responsible for the formation of **pith rays or medullary rays.** These are made up of parenchyma. **They conduct water and food in radial direction.**
- **Cork cambium** is developed **from the pericycle** in roots. **Cork** is formed towards the outside and **secondary cortex** is formed towards the inner side by the cork cambium. Lenticels are also found in roots but less in number as compared to stem. Cortex completely degenerates in roots after the secondary growth of one or two years due to the pressure of cork, whereas in stem, it degenerates after the long duration.
- Secondary growth is essential in roots to provide strength to the growing aerial parts of the plants and fulfil the requirement of water and minerals.
- Generally clear annual rings are not seen in roots because roots are not affected by the changes of environment.
- Secondary growth is not found in monocot roots.
- **In dicot roots, all cambia and pith rays (medullary rays) are totally secondary in origin.**

Stele :

- **All the tissues which are present inside the endodermis constitute the stele.**
- The stele is the whole central mass of vascular tissue (vascular cylinder) with or without pith surrounded by endodermis. Stele is surrounded by endodermis but endodermis is originally the part of cortex. It is not a part of stele. **Van Tieghem** and **Douliot** put forwarded the **concept of stele**/stelar theory. Different types of steles are found in pteridophytes.

TG: @Chalnaayaaar

Golden Key Points

- In roots, the parenchymatous cells which lie between the xylem and the phloem are called conjunctive tissue.
- The tissues involved in secondary growth are the two lateral meristems i.e. vascular cambium and cork cambium.
- During secondary growth the primary xylem however remains more or less intact, in or around the centre.
- Bark is a non-technical term that refers to all tissues exterior to the vascular cambium.
- In monocot stem, water containing cavities are present within the vascular bundles.
- The growth of the roots and stems in length with the help of apical meristem is called the primary growth. Apart from primary growth most dicotyledonous plants exhibit an increase in girth. This increase is called the secondary growth. The tissues involved in secondary growth are the two lateral meristems: vascular cambium and cork cambium.
- The meristematic layer that is responsible for cutting off vascular tissues – xylem and pholem – is called vascular cambium. In the young stem it is present in patches as a single layer between the xylem and phloem. Later it forms a complete ring.
- In dicot stems, the cells of cambium present between primary xylem and primary phloem is the intrafascicular cambium. The cells of medullary rays, adjoining these intrafascicular cambium become meristematic and form the interfascicular cambium. Thus, a continuous ring of cambium is formed.
- In eustele, vascular bundles are arranged in a ring.
- In atactostele, vascular bundles are scattered in ground tissue.
- **Cricket bat** → from ***Salix*** [Willow] wood
- **Hockey blade** → from ***Morus*** [Mulberry] wood
- **Billiards's ball** → ***Phytelophus*** (Ivory Palm)
- **Violin** → ***Picea*** (Spruce)
- **Monarch** Condition → in ***Trapa*** root
- **Triarch** Condition → in ***Pisum*** root
- **Tetrarch** Condition → in ***Helianthus annuus*** (Sunflower) and ***Cicer arietinum*** (Gram) root
- **Chewing gum** is made by latex of ***Achras sapota***.
- **Cystolith** containing cells are found in the upper epidermis of ***Ficus*** leaf, called **lithocytes/ Lithocysts**.
- Xylem / Lignin is stained by **safranin (Red)** and phloem is stained by **fast green**.
- Transition of exarch bundles of root to endarch bundles of stem occurs in **hypocotyl**.
- In some plants like date palm increase in length as well as girth of stem due to **primary thickening meristem**.

TG: @Chalnaayaaar

BEGINNER'S BOX-2

PRIMARY INTERNAL STRUCTURE TO SECONDARY GROWTH

1. Monocot roots are usually :-
(1) Diarch (2) Triarch (3) Tetrarch (4) Polyarch

2. In which of the following sclerenchymatous pericycle is found in the form of semi-lunar patches:
(1) Sunflower stem (2) Sunflower root (3) *Zea mays stem* (4) *Cucurbita stem*

3. Position of protoxylem in the vascular bundle of dorsiventral leaf is :-
(1) Adaxial (2) Abaxial
(3) Both (1) & (2) (4) Towards dorsal surface

4. The innermost layer of bark is :-
(1) Primary phloem (2) Secondary phloem (3) Periderm (4) Phelloderm

5. Lenticels are found in :-
(1) All plants (2) Woody trees (3) Monocots (4) All vascular plants

6. Match the following :-

Column I		Column II	
a.	Hypodermis in dicot stem	(i)	Absent
b.	Pericycle in dicot stem	(ii)	Parenchymatous
c.	Ground tissue in monocot stem	(iii)	Collenchymatous
d.	Phloem parenchyma in monocot stem	(iv)	Heterogenous

(1) a (iv), b (i), c (iii), d (ii) (2) a (i), b (ii), c (iv), d (iii)
(3) a (iii), b (iv), c (ii), d (i) (4) a (ii), b (iii), c (i), d (iv)

7. The stomata in an isobilateral leaf
(1) Are present only on the adaxial epidermis
(2) Are present only on the abaxial epidermis
(3) Are absent on both the surfaces of the epidermis
(4) Are present on both the surfaces of the epidermis

8. During water stress, the bulliform cells
(a) Become turgid (b) Become flaccid
(c) Make the leaves curl inwards (d) Make the leaf surface exposed
The correct options are
(1) (a) and (c) (2) (b) and (d) (3) (a) and (d) (4) (b) and (c)

BEGINNER'S BOX ANSWERS KEY

BEGINNER'S BOX-1	Que.	1	2	3	4	5	6	7	8	9	10
	Ans.	2	4	1	4	1	3	1	1	2	2
	Que.	11	12	13	14						
	Ans.	1	3	1	4						

BEGINNER'S BOX-2	Que.	1	2	3	4	5	6	7	8
	Ans.	4	1	1	2	2	3	4	4

TG: @Chalnaayaar

Tissue

Meristematic tissue
Having Cell division capacity

- **Apical meristem**
  - Present at root and shoot apex
  - Primary meristem
- **Intercalary meristem**
  - Present in between mature tissues
- **Lateral meristem**
  - Parallel to longitudinal axis of plants
  - Primary and **secondary** **(Mainly)**

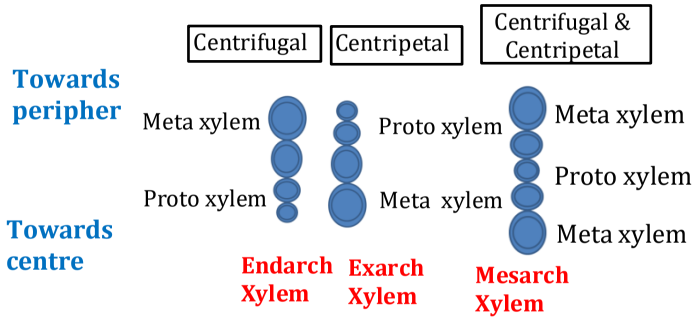
Permanent tissue
No cell division capacity

- **Simple permanent**
  - Made up of only one type of cells (Homogenous tissue)
  - **Parenchyma**
    - Thin walled
    - Form major bulk of plant organ
    - Storage, Secretion, photosynthesis
  - **Collenchyma**
    - Localized thickening
    - Present in Young dicot stem
    - Living mechanical tissue
  - **Sclerenchyma**
    - Highly thickened wall
    - Lignified wall
    - Dead mechanical tissue
- **Complex permanent**
  - Made up of more than one type of cells (Heterogenous tissue)
  - **Xylem**
    (Sap conduction & Mechanical support)
    Tracheids } Dead
    Vessels } Thick walled
    X. Fibres } Lignified
    X. Parenchyma- Living
    - Tracheids and vessels are sap conducting elements
  - **Phloem**
    (Food conduction)
    Sieve tube } Living
    Companion cells } Living
    P. Parenchyma
    P. Fibres - Dead
    - Sieve tube and companion cells are found in angiosperms
    - Sieve cells & Albuminous cells are found in gymnosperms & pteridophytes.

Tissue system

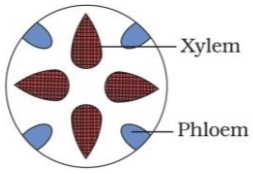
- **Epidermal tissue system**
  - Protection
  - Epidermis, root and stem hair
  - Parenchymatous
- **Ground tissue system**
  - Major part of plant organ
  - Consists of Simple permanent tissues (Mainly
- **Vascular tissue system**
  - Conducting tissue
  - Xylem and phloem
  - Water, mineral

Types of development of primary xylem :-



Types of vascular bundles

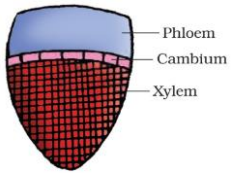
Radial



eg.Roots

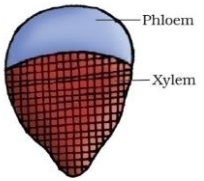
Conjoint collateral

Open



eg.Dicot stem

Closed



eg.Monocot stems, Dicot and monocot leaves

ESSENCE
TG: @Chalnaayaar
ALLEN DIGITAL
ALLEN Digital
www.allendigital.in

Dicotyledonous stem	Monocotyledonous stem
Presence of Trichomes	Absence of Trichomes
Collenchymatous hypodermis	Sclerenchymatous hypodermis
Pith is large & well developed	pith is Undifferentiated
Vascular bundles are open and arranged in a ring	Vascular bundles are closed and scattered

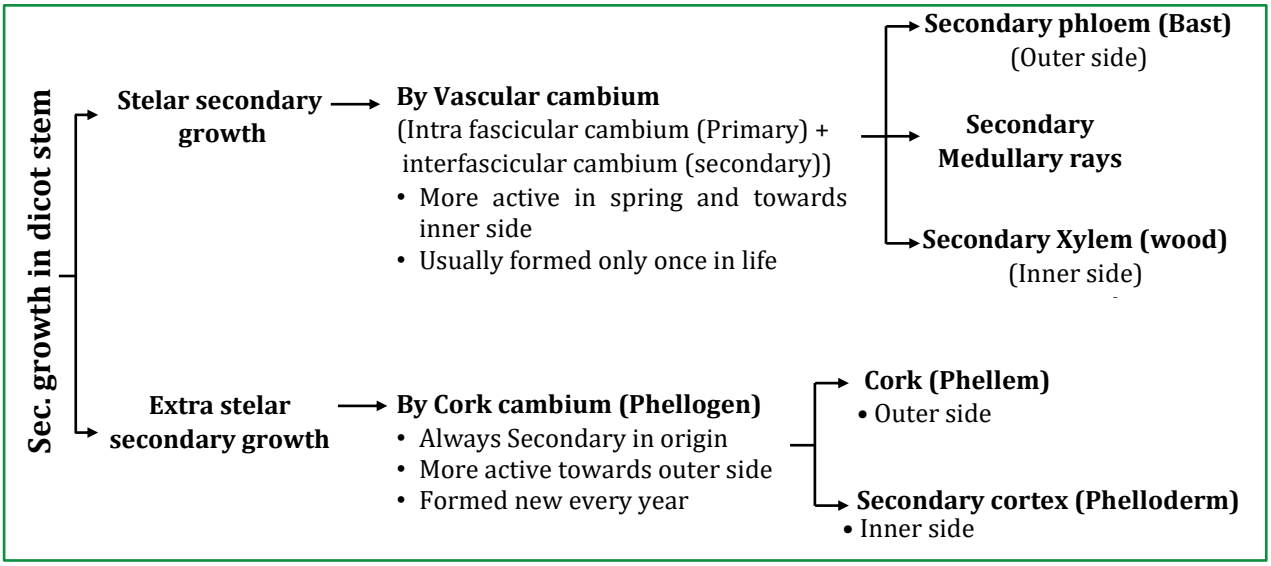
- Ground tissue is undifferentiated in Monocotyledonous stem.

Dicotyledonous root	Monocotyledonous root
Usually 2 to 4 xylem bundles	Usually More than 6 xylem bundles
Hexagonal vessels	Oval shaped vessels
Pith is small or inconspicuous	Pith is large and conspicuous

- In a dorsiventral leaf, mesophyll is differentiated into spongy and palisade mesophyll.
- In a isobilateral leaf, mesophyll is not differentiated into spongy and palisade mesophyll.
- In both types of leaves, xylem is towards adaxial surface while phloem is towards abaxial surface
- Heart wood : Physiologically inactive, Dark brown, Central part of secondary xylem
- Sap wood : Physiologically active, lighter in colour, peripheral part of secondary xylem

Spring wood	Autumn wood
Large number of secondary xylem elements	Fewer secondary xylem elements
Vessels with wide lumens	Vessels with narrow lumens
Lighter in colour	Darker in colour
Lower density	Higher density

- Phellem, Phellogen & Phelloderm are collectively termed as **Periderm**.
- Secondary phloem and periderm are included in bark.
- In dicotyledonous stem, vascular cambium is partly primary and partly secondary in origin.
- In dicot root vascular cambium is completely secondary in origin
- In dicot stem cork cambium usually develops in cortical region (usually from hypodermis) while in dicot root it is usually originated from pericycle.
- Estimate Age of a tree can be determined by counting the annual rings.


Sec. growth in dicot stem
Stelar secondary growth
By Vascular cambium
(Intra fascicular cambium (Primary) + interfascicular cambium (secondary))
• More active in spring and towards inner side
• Usually formed only once in life
Secondary phloem (Bast)
(Outer side)
Secondary Medullary rays
Secondary Xylem (wood)
(Inner side)
Extra stelar secondary growth
By Cork cambium (Phellogen)
• Always Secondary in origin
• More active towards outer side
• Formed new every year
Cork (Phellem)
• Outer side
Secondary cortex (Phelloderm)
• Inner side